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Bulletin No. 335 - Reclamation of Saline-Alkali Soils by Leaching: Delta Area, Utah

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DELTA AREA, UTAH

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UTAH AGRICULTURAL EXPERIMENT STATION
LOGAN, UTAH
In Cooperation with the
U. S. REGIONAL SALINITY AND
RUBIDOUX LABORATORIES
RIVERSIDE, CALIFORNIA

THIS BULLETIN is a joint contribution of the U. S. Regional Salinity and Rubidoux Laboratories and the Utah Agricultural Experiment Station which reports one phase of a cooperative investigation performed under a memorandum of understanding among the Utah Agricultural Experiment Station, the U. S. Regional Salinity and Rubidoux Laboratories, and the Millard County drainage districts. The work of the U. S. Regional Salinity and Rubidoux Laboratories was done under an allotment from the special research fund authorized by Title 1 of the Bankhead-Jones Act of June 29, 1935, and in cooperation with the agricultural experiment stations of Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, Wyoming, and the Territory of Hawaii.

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Agricultural Experiment Station
Utah State Agricultural College
Logan, Utah
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TABLE OF CONTENTS

SUMMARY

A TWO-YEAR leaching study was conducted in the Delta Area, Utah, to determine the requirements for reclaiming saline and alkali soils. Studies were made at three widely separated locations on different soil types. Plots 30x40 feet were leached by ponding water on the surface. The leaching treatments consisted of: (1) light leaching - 1 foot of water, (2) medium leaching - 2 feet of water, (3) heavy leaching - 4 feet of water, and (4) heavy leaching - 4 feet of water plus gypsum at the rate of 5 tons per acre.

After leaching, fall wheat was grown on the experimental plots and the yields for the various treatments determined. Three 6-inch irrigations, applied to all plots were required to mature the crop. The salinity status of the leaching plots was determined by chemical measurements before leaching, after leaching, and three times during the cropping period.

Before leaching, these soils contained excessive amounts of soluble salts, and the exchangeable-sodium-percentage was high. The salt concentration was highest at the surface and diminished with depth. On the basis of salt content and exchangeable-sodium-percentage, these soils may be classified as saline-alkali. Such soils usually require chemical amendments for reclamation unless sufficient soluble calcium in the form of gypsum is present in the surface soil. The soils at the experimental sites contained gypsum in amounts ranging from 2 to 23 tons per acre foot. The amount present was sufficient for reclamation purposes. Infiltration rates were sufficiently high for successful leaching. At two locations, the addition of gypsum did not improve infiltration, but at the third location, the infiltration rates were approximately doubled with the addition of gysum.

The amount of salt removed from the soil increased with the amount of water applied. One foot of water materially reduced the salt content of the surface foot of soil but accomplished little leaching below that depth. The application of 4 feet of water gave the greatest reduction in salt content throughout the root zone.

Yields varied inversely with the residual salinity of the soil. The relation between yield and salinity was found to be of hyperbolic character where yields increased more and more rapidly as salinity decreased. At the low salt levels, slight reductions in salt content resulted in large increases in yield.

The relation between yield and the amount of leaching water was found to be approximately linear. Yields increased directly with the amount of water applied for leaching at average rates of 10.2, 8.8, and 4.7 bushels per acre foot of water applied at site A, C, and D, respectively. Average yields of from 41 to 43 bushels per acre were obtained on the plots leached with 4 feet of water compared to yields of from 1 to 29 bushels per acre where no leaching water was applied.

FOREWORD

Cooperative investigations on drainage and reclamation of salted soils in the Delta Area, Utah, were undertaken by the Utah Agricultural Expericent Station, the U. S. Regional Salinity Laboratory, and Millard County Drainage Districts Nos. 1, 2, 3, and 4, under a memorandum of understanding effective January 1, 1946.

This investigation comprises project no. 250 of the Utah Agricultural Experiment Station, R. H. Walker, director; and project no. 50-46-1 of the U. S. Regional Salinity Laboratory, H. E. Hayward, director.

The objectives of the investigations covered by the memorandum of understanding were:

1. To study the effectiveness of present methods of drainage; tile and open drains.
2. To determine the possibilities of pumping from wells as a method of drainage in the Delta Area and the possibility of using the pumped water for irrigation.
3. To determine practical and economical methods of reclaiming unproductive saline and alkali soils of the area by leaching.

The leaching phase of these investigations has been completed and the results are reported herewith. The first and second phases concerned with the effectiveness of present drainage methods and the possibilities of pumping for drainage are in progress, but are not included in this report. However, it must be kept in mind that drainage and leaching are inseparable and must be considered as integral parts of an over-all reclamation program for the Delta Area.

RECLAMATION OF SALINE-ALKALI SOILS BY LEACHING — DELTA AREA, UTAH

R. C. Reeve, L. E. Allison, D. F. Peterson, Jr.[1]

INTRODUCTION

Salinity is a problem of irrigation agriculture and is recognized as a serious threat to crop production in the Western States. All water used for irrigation, whether diverted from surface streams or pumped from wells, contains dissolved salts in amounts varying from a few hundred pounds to several tons per acre-foot (8,23).[2] Salts accumulating in the root zone of the soil, as water is removed by crops and by surface evaporation eventually, may restrict crop yields. Extensive areas of land in the Western States, which were at one time productive under irrigation, have been abandoned because of the development of saline or alkali conditions (15, 23). This outright abandonment of lands not only materially reduces total crop production but increases the burden on lands that are productive, by way of increased taxes, and per-acre cost of reclamation and construction. Depreciated land values and unfavorable social and economic changes often result. In addition to losses from abandonment of lands resulting from intense saline or alkali conditions, there are losses from reduced crop yields caused by lesser degrees of salinity. The latter go unrecognized and unheeded over large areas of irrigated land. It has been estimated that such losses may amount to as much as 10 to 25 percent (13).

Numerous reclamation investigations have been made in the Western States during recent years (1, 2, 3, 4, 5, 11, 19, 20, 21, 22, 27, 29, 32). Hilgard's early studies of arid lands in California (14) revealed that the unproductivity of "alkali" soils is caused by the accumulation of excessive soluble salts and that different kinds of salts produce different degrees of plant injury. Hilgard devoted extensive study to the origin and mode of accumulation of soluble salts in soils as well as to methods of reclamation. He recognized two classes of "alkali" land; namely, "white-alkali" and "black-alkali," the former containing neutral salts such as chlorides and sulfates of calcium, magnesium, and sodium and the latter containing chiefly the alkaline salts of sodium carbonate and sodium bicarbonate, with or without small amounts of neutral salts of sodium. Following Hilgard's pioneer work

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[2]Numbers refer to Literature Cited page 41.

in this field, Kelley and Brown in California (18) and de Sigmond in Hungary (26) emphasized the significance of base exchange reactions in alkali land reclamation. Based on extensive studies of different kinds of "alkali" soils, Kelley (20) pointed out that the clay and humus colloids of the soil react with (adsorb) sodium from the sodium salts present, thereby producing a physical condition of the soil which in itself is harmful to crops and which must be overcome before the soil can be truly reclaimed. Reclamation of soils so affected (21) requires the addition of chemical amendments such as gypsum or sulfur, or combinations of these with manure, followed by heavy leaching. Although iron sulfate and potassium alum have been shown to be effective in reclamation of "alkali" soils (19) their cost is prohibitive. However, not all so-called "alkali" soils require chemical treatment for improvement. Thomas (29) found that certain soils in the Imperial Valley, California, were reclaimed sufficiently to produce large crops merely by heavy leaching with Colorado River water.

It is recognized that some ions are toxic to plants (12). On the other hand, the detrimental action of salts results primarily from the binding action on water, or osmotic effect. Plants remove water from the soil by osmosis; and, as the salt concentration of the soil water increases, the amount of water available to plants decreases. As salts concentrate in the root zone, this condition is intensified until the crops yield poorly or even fail to survive. The only solution in such cases is to leach the salt beyond the root zone by applying excess water.

The meaning of the terms "saline soil" and "alkali soil" has been variable, depending on locality. The term "alkali" is often used in a broad sense to include both "white" and "black" alkali as defined by Hilgard. In this report the meaning of terms will be in accordance with the usage of the U. S. Regional Salinity Laboratory (31). The term "saline soil" denotes a soil for which the conductivity of the saturation extract is greater than 4 millimhos per cm, and the exchangeable-sodium-percentage is less than 15. The term "alkali soil" refers to a soil having an exchangeable-sodium-percentage greater than 15, either with or without appreciable amounts of salt. Where the soil is both saline and alkali, it is referred to as a saline-alkali soil. The term "salted soil" refers to a soil having characteristics caused by exposure to excessive amounts of soluble salts. This term covers both saline and alkali soil conditions.

The investigation herein reported comprised a two-year leaching study conducted to determine the possibilities of restoring the saline-alkali soils of the Delta Area to a state of high productivity. Details of procedure and results obtained are reported and it is hoped that the findings may have practical application in the arid West in alleviating saline and alkali conditions.

THE DELTA AREA

THE DELTA AREA comprises about 120,000 acres located near the delta of the Sevier River in the west-central part of Utah. It is a part of the bottom of former Lake Bonneville and is a rather smooth plain with little slope, ranging from 5 to 20 feet per mile.

The agricultural conditions of the area have been studied and reported by various agencies. The Division of Soil Survey, U. S. Department of Agriculture, conducted a soil survey of the area, which was published in 1922 (28). The Utah Agricultural Experiment Station has reported on the drainage and irrigation, soil, economic, and social conditions in the Delta Area in a series of four bulletins, in 1935, 1936, and 1939 (7, 15, 17, 30). The reader is referred to these bulletins for more specific information regarding the location, topographic features, agricultural, economic and social conditions of the area. The history of irrigation in the Delta Area and the development of drainage difficulties are given in some detail by Israelsen (15). Irrigation began in the area about 1860 with considerable expansion taking place about 1905.

It was not until about 1916 that difficulties arising from inadequate drainage and high salinity began to be evident. During the years 1916 to 1920, the area was organized into four drainage districts comprising a total of 82,400 acres, and drainage systems consisting of tile and open drains were constructed. Considerable relief resulted from the construction of the drainage systems and for a number of years the agricultural and economic conditions of the area were much improved. During the drought years of 1930 to 1934, when the irrigation water supply was limited, the drainage systems were not adequately maintained and many of them, especially the tile drains, fell into disrepair. In recent years, with more abundant water supplies, lack of adequate drainage has again become a serious threat to crop production. Seepage losses from irrigation canals have contributed materially to the ground water and have increased the need for adequate drainage. Losses of from 2.1 to 11.0 percent of inflow per mile from Delta Area canals have been reported (16). The need for drainage has been recognized by the people of the area and during the past eight to ten years the drainage districts constructed additional open drains to replace non-functioning tile drains wherever possible. Even though open drains require large amounts of land for rights-of-way, there has been a tendency to construct them instead of tile drains since they are more easily maintained.

Four mutual irrigation companies in the area furnish water from the Sevier River to irrigate approximately 45,000 acres of land. This water is high in salt which intensifies the salinity problem. Chemical

Table 1. Chemical analyses of irrigation and drainage waters from the Delta Area, Utah.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
					Soluble ions											
					Cations m.e./1.					Anions m.e./1.						
Kind of water	EC x 10^3 at 25° C.	pH	Total salts ppm	TAF	Ca	Mg	Na	K	Total	CO_3	HCO_3	SO_4	CL	NO_3	Total	Sodium percentage
Irrigation*	2.27	8.0	1580	2.1	4.3	7.3	12.6	0.01	24.2	0.4	4.5	8.5	12.0	....	25.4	52
Irrigation†	2.65	8.4	1680	2.3	3.3	7.5	15.2	0.3	26.3	0.6	4.1	8.3	14.0	....	27.0	57
Drainage‡	33.0	7.4	22,900	31.1	42.	82.	259.	1.6	385.	0.	8.2	84.8	294.	1	388.	67
Drainage§	22.9	7.3	15,800	21.5	22.6	26.5	189.	1.2	239.	1.2	7.5	80.5	177.	0.5	267	79
Drainage‖	12.0	8.1	8200	11.2	17.5	28.7	88.8	....	135.0	0.4	2.5	45.0	88.0	....	135.9	66

Locations of Water Samples

*From Gunnison Bend Reservoir. Sampled June 20, 1942, by J. E. Christiansen.

†From Delta B Canal at flume over Sevier River, S¼ cor. of sec. 25, T. 16 S, R. 7 W. Sampled in September, 1945, by J. E. Christiansen.

‡From south side of new drain where 6" tile was broken, sec. 1, T. 18 S., R. 7 W. Sampled 7-27-45 by R. G. Rickenbach.

§From north side of new drain. Same location as sample above. Sampled 7-27-45 by R. G. Rickenbach.

‖From Millard County Drainage District No. 3 open drain outlet D at a point where the center line of sec. 2, T. 16 S., R. 8 W. intersects township line between 15 and 16 S. Sampled September 1942, by R. C. Reeve.

analyses of the irrigation water from the Sevier River and several drainage waters from open drains in the Delta Area are given in table 1.

Various investigators have classified irrigation waters as to their suitability for irrigation on the basis of total salt content, sodium percentage, and boron content. Magistad and Christiansen (23) grouped irrigation waters into three classes: (1) Waters with conductivity of less than 1.0 millimho per centimeter, total salt content of less than 700 parts per million, or a sodium percentage less than 60. Such waters are considered as excellent to good, and suitable for most crops under most conditions. (2) Waters with conductivity of from 1.0 to 3.0 millimhos per centimeter, total salt content ranging from 700 to 2000 parts per million, and a sodium percentage of 60 to 75. These waters are considered as good to injurious but probably harmful to the more sensitive crops. (3) Waters with conductivity of over 3.0 millimhos per centimeter, total salt content greater than 2000 parts per million, or a sodium percentage greater than 75. Waters of this class are generally considered injurious to unsatisfactory, probably harmful to most crops and unsatisfactory for all but the most tolerant. If water falls in class 3 on any basis, i.e., conductivity, salt content, or percentage of sodium, it should be classed as unsuitable under most conditions. Although this grouping also includes boron content as a criterion for classifying irrigation waters, the tolerance limits are not given above because boron content is not critical in the Delta Area.

The conductivity of the Delta irrigation water as shown in table 1 is from 2.27 to 2.65 millimhos per centimeter, and the sodium percentage is from 52 to 57. On the basis of the above classification, the Delta water is class 2 water. The salt input to the soil is from 2.1 to 2.3 tons per acre-foot of water applied. The annual requirement of water for most crops in the Delta Area is from 1½ to 3 acre-feet per acre (15). If only the amount of water required for use by the crop is applied to the land, i.e., there is no loss of water by drainage, there will be an accumulation of from 3 to 7 tons of salt per acre annually. This rate of accumulation is sufficient to change a salt-free soil to a saline soil throughout the root zone in from 3 to 5 years.

Soils adsorb sodium from irrigation waters and retain it in an exchangeable form, depending upon the salt content and sodium percentage of the water in contact with the soil. Sevier River water contains from 25 to 27 milliequivalents of salt per liter, or 1600 to 1700 parts per million, and has a sodium percentage averaging about 55. If water of this composition is continuously percolated through a soil until equilibrium is established, the salinity of the soil water will be that of the irrigation water and the exchangeable-sodium-percentage will be approximately 8 (6, 31). A soil so treated would be non-saline and non-alkali. Under irrigation conditions, however, soluble salts accumulate in the root zone owing to removal of water by plants and by surface evaporation. Since calcium and magnesium ions tend to precipitate in the soil as calcium and magnesium carbonate and to some extent as calcium sulfate or gypsum, which are relative insoluble, the soil becomes predominately sodium. In order to maintain equilibrium, the soil colloids adsorb sodium in exchange for calcium and magnesium and the exchangeable-sodium-percentage greatly increases, often attaining values of from 40 to 50 percent. Based on these known facts, the use of Sevier River water for irrigation purposes under conditions of little or no salt removal by leaching may be expected to render the soil alkali within relatively few years.

The data of table 1 show that the drainage waters of the Delta Area, which reflect the composition of the soil solution below the water table, are extremely saline, containing about 11 to 31 tons of salt per acre-foot. This is from 5 to 15 times as much salt as is contained in the irrigation water and is ample evidence of the need for improved drainage and for leaching.

There must be a favorable balance between the amount of salt brought into the area by the irrigation water and the amount removed from the root zone by drainage in order to maintain permanent agriculture. Actually under most irrigation conditions some leaching occurs, since it is impossible to apply only the amount required for the crop. With water of moderately high salt content such as the Delta irrigation water considerable leaching must occur if a favorable salt balance is to be maintained. This is especially true where shallow water tables exist and there is a continuous upward movement of highly saline ground water to the soil surface.

EXPERIMENTAL PROCEDURE

THREE HIGHLY saline soils, at locations separated as widely over the area as practical, were selected for experimental leaching trials. Four leaching treatments, consisting of heavy, medium, and light water applications and one gypsum treatment combined with the heavy water applications were applied to the soil at each site. The effectiveness of the various treatments in removing soluble salts and exchangeable sodium from the soil was measured by: (1) chemical analyses of the soils before and after treatment; and, (2) by the response of crops grown on the soils.

Selection of Leaching Sites

A preliminary survey in which salinity determinations and infiltration tests were run was made as a basis for selection of suitable locations for the leaching studies. Several sites in the Delta Area were investi-

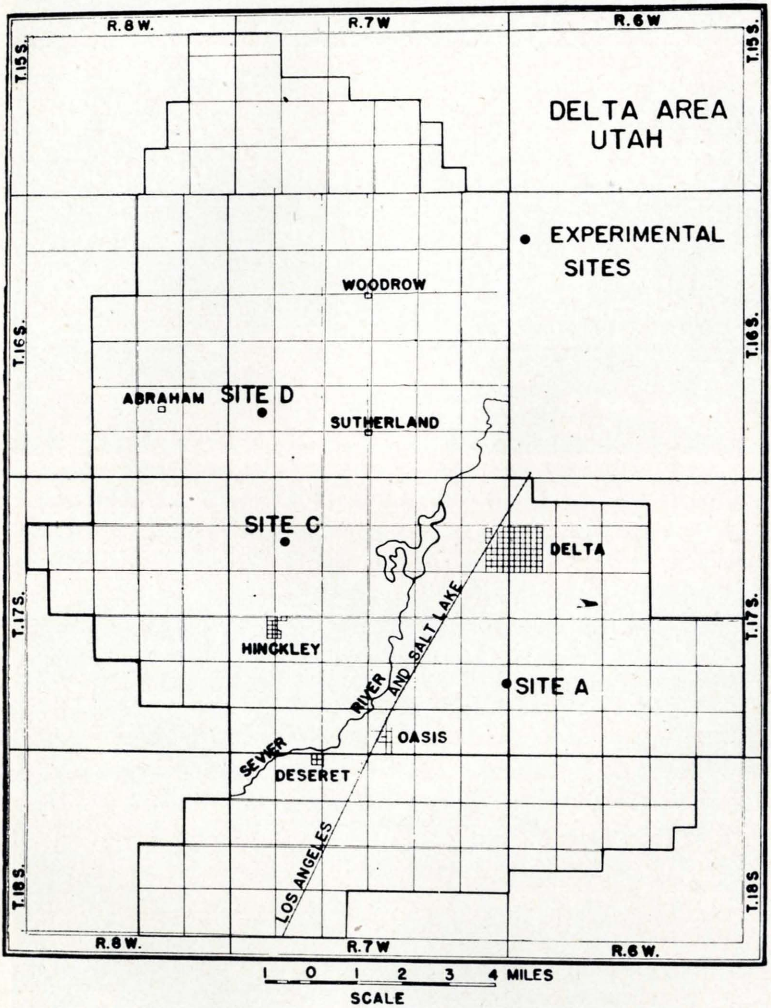

Fig. 1. Map of the Delta Area, Utah, showing location of the three experimental leaching sites

gated and three of these, designated A, C, and D, were selected (fig. 1). Selections were made on the basis of adequacy of drainage, degree of salinization, uniformity of salt distribution, soil type, accessibility, availability of irrigation water, topographic suitability for leaching, and cooperative attitude of the land owner. One additional location near Oasis designated site B was eliminated as a possibility for experimental leaching because of inadequate drainage conditions. Each ex-

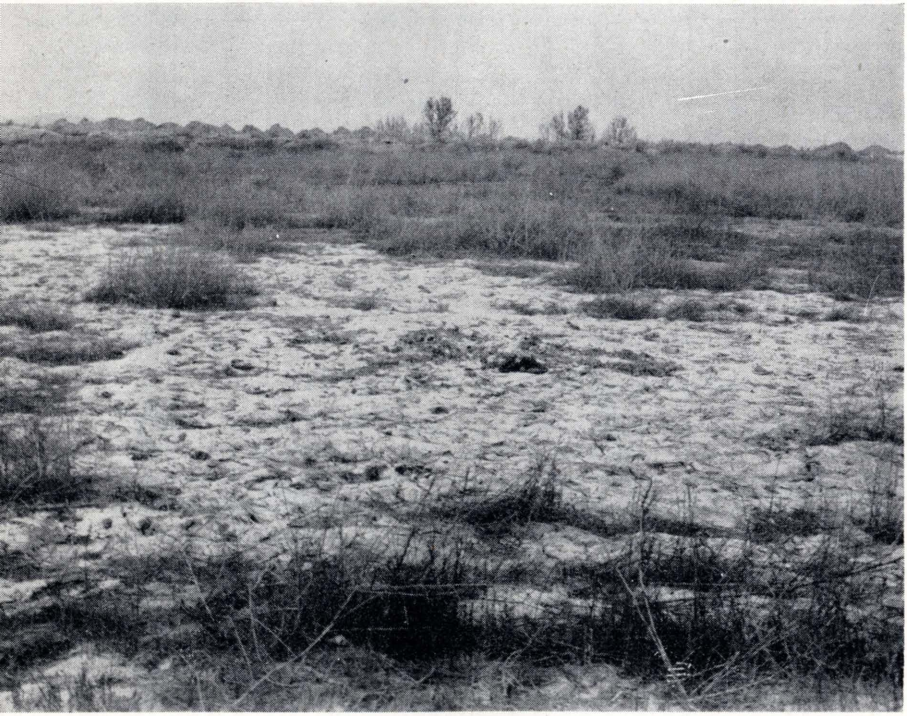

Fig. 2. (Upper) The condition of the surface soil at site A before leaching
Fig. 3. (Lower) Site C before leaching showing surface accumulation of salt and growth of halophyte, *Bassia hyssopifolia*

perimental site was located near a deep open drain to insure adequate drainage.

Site A—Experimental plots were located three miles south of Delta on the Owen Gardner farm, formerly known as the Stapley farm. They comprised approximately one acre of land in a highly salted area mapped as Woodrow clay loam (28), and located 200 feet north of the center line of the open drain in the SE¼ NE¼, Section 25, Twp. 17 South, Range 7 West. The field in which the plots were located had been idle for many years and was highly saline in the surface layers owing to the existence of a shallow water table which was 4½ feet below ground surface in 1946. A white crust and salt puffs characteristic of a highly saline soil appeared on the surface (fig. 2).

Site C—Experimental plots were located two miles north of Hinckley on the Grant C. Robinson farm, formerly known as the Sawyer place. They comprised approximately one acre of land mapped as Oasis silty clay loam (28), located 358 feet south of a deep open drain in the SE¼ NW¼, Section 8, Twp. 17 South, Range 7 West. This land was cultivated at one time but had been out of production for several years. A white salt crust was evident and the water table was at a depth of about 5½ feet below the surface in 1946. Surface conditions at this site before leaching are shown in fig. 3.

Site D—Experimental plots were located two miles east of Abraham on the Morgan May farm. They comprised about one acre of land mapped as Gordon clay (28), located 102 feet south of a deep open drain in the NW¼ SE¼, Section 30, Twp. 6 South, Range 7 West. The land at this site had been idle for some time, however, cultivation had been more recent at this location than at sites A and C. The water table was about 7½ feet below ground surface prior to leaching.

Plot Layout

At each of the experimental sites, twenty leaching plots 30 by 40 feet were constructed in two tiers of 10 plots each as shown in figure 4. Earth borders were erected to form individual basins, and ditches were constructed to supply water to the plots. Control gates were used in the supply ditch to facilitate the application of water to the plots.

Treatments

Five leaching treatments replicated four times were applied at each of the three sites. The replications were randomized as shown in figure 4, so as not to occur on adjacent plots or on plots adjacent diagonally. The treatments were as follows:

(1) No leaching..(check)
(2) Light leaching..1 ft. of water
(3) Medium leaching....................................2 ft. of water
(4) Heavy leaching..4 ft. of water
(5) Heavy leaching plus gypsum..........4 ft. of water plus 5 tons gypsum per acre

Gypsum of high purity was obtained from a deposit near Meadow, Utah, for use in these experiments. The required amount, 275 pounds per plot of 1200 square feet (5 tons per acre), was spread uniformly over the surface of the assigned plots prior to leaching. No attempt was made to work the gypsum into the soil.

BLOCK			II					I		
PLOT	19	17	15	13	11	9	7	5	3	1
TREATMENT	(4)	(5)	(3)	(1)	(2)	(5)	(3)	(4)	(2)	(1)

BLOCK			IV					III		
PLOT	20	18	16	14	12	10	8	6	4	2
TREATMENT	(2)	(4)*	(1)*	(5)	(3)	(4)	(2)	(1)	(5)	(3)

*Treatments for plots 16 and 18 reversed at site C.

Fig. 4. Plot layout showing randomization of treatments in blocks. (1) No leaching, check, (2) light leaching, 1 ft. water, (3) medium leaching, 2 ft. water. (4) heavy leaching, 4 ft. water, (5) heavy leaching plus gypsum, 4 ft. water plus 5 tons gypsum per acre

Leaching Operations

Water applications consisting of approximately 3 to 6 inches (depth) were made successively to each plot until the total assigned depth of water had been applied. The plots at site C during application of water are shown in figure 5. An attempt was made to keep the ground in each basin covered with water so that the leaching of the total amount through the soil was continuous. The water was measured to the plots with a Parshall flume installed in the head ditch.

Infiltration Tests

Rates of infiltration were obtained from periodic readings of the depth of water on each plot throughout the leaching period. A hook gage suspended from 2x2 inch wooden stakes installed in each plot, was used for this purpose.

Soil Sampling

All plots at each experimental site were sampled before leaching, after leaching, and on three subsequent occasions during cropping. The samples were obtained with a soil tube by making five borings per plot

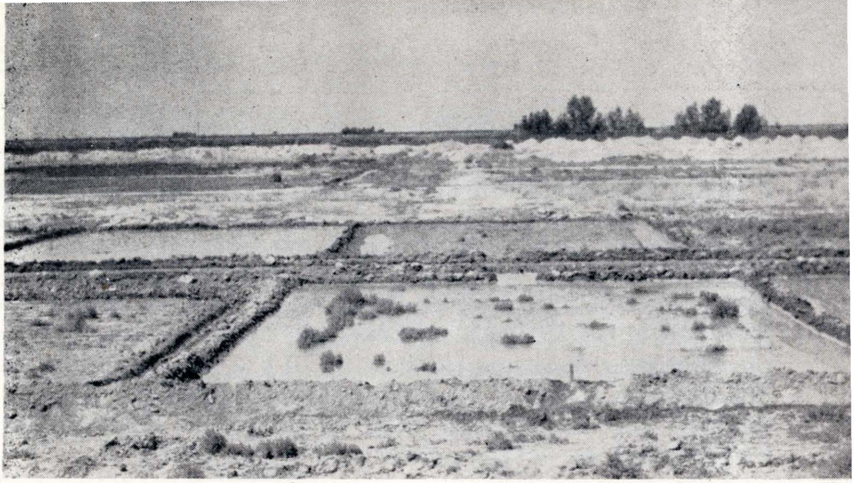

Fig. 5. View of plots at site C during leaching operations

to a depth of four feet and combining the borings by one-foot depths. Thus, for any single plot for any single sampling four composite samples were obtained. At the initial sampling prior to leaching the boring sites were located with stakes, one in the center of each plot and the other four midway between the center and the corners. All subsequent borings were made within a radius of one foot from the initial holes. Where a considerable salt crust was present, such as at sites A and C, special precaution was taken to get a representative sample of the surface soil. Frequently the moisture content of the soil was at or near saturation at the lower depths. Samples were placed in waxed paper bags to avoid loss of either sample or salt during shipment from the field to the laboratory.

Cropping

After completion of the leaching, all borders and ditch banks were leveled and the entire experimental area at each site (approximately one acre) was planted to wheat. Large amounts of salt had accumulated in the earth borders during the leaching, therefore, care was exercised to level the borders without spreading the soil over the surface of the plots. At site A the seedbed was prepared by plowing to a depth of 6 inches followed by disking to break up the large clods. At sites C and D the seedbed was prepared by disking to a depth of from 4 to 8 inches. All plots received a uniform application of a 16-20-0 fertilizer (ammonium phosphate sulfate) at the rate of 250 pounds per acre at time of seeding. This was broadcast by hand at site A and was drilled into the soil with a grain drill at sites C and D.

Wasatch wheat, a variety developed at the Utah Agricultural Experiment Station, was sown by drilling at each site at the rate of 2 to 2½ bushels per acre. An area larger than the original leaching plots was planted to provide an outside border ranging from 7 to 30 feet on all sides. The sites were corrugated and borders constructed to facilitate irrigation. The borders were made to coincide with the previous leaching borders. Three soil-moisture tensiometers were installed at each site to serve as a general guide for irrigation. They were installed at a depth of 12 inches in plots nos. 8 (1 foot leaching treatment), 12 (2 foot leaching treatment), and 17 (4 foot leaching plus gypsum treatment). Irrigations were made when the tensiometers approached their maximum readings, i.e., 0.7 to 0.8 atmosphere. The first irrigation of 6 to 8 inches was immediately following planting in the latter part of September 1946. Two additional 6-inch irrigations were required, one in May and the other in June 1947.

Harvest

Following planting the wheat germinated and made normal growth during the fall months. Spring growth began about the middle of March 1947. The grain was harvested about the middle of July. Measurements of yields were obtained by taking five quadrates, one-yard square, from each plot and the weight of grain plus straw was obtained. In order to make the sample sufficiently large for threshing, all quadrates for each plot were combined. In some cases where the stand on the check plots was extremely variable entire plots were harvested instead of the usual five quadrates.

RESULTS

Infiltration Rates

IF DRAINAGE is adequate, infiltration rates are related primarily to the permeability of the soil and serve to indicate its suitability for irrigation and crop production. For saline and alkali soils the rate at which the soil will transmit water is important in determining whether or not it is leachable and hence whether it can be reclaimed. In the leaching process the salts are taken in solution by the water as it passes down through the soil and out through the drainage ways. If water is transmitted readily, removal of salt is facilitated. Furthermore, the time required for an adequate amount of water to percolate through the soil may well limit the feasibility of reclamation.

Alkali soils, those containing excessive amounts of exchangeable sodium, disperse upon leaching and often become highly impermeable as the soluble salts are removed. In this case, chemical amendments are required to bring about improvement of the soil by replacing the exchangeable sodium with calcium. Gypsum and, under certain conditions, sulfur may be used for this purpose, but reclamation is more rapid when gypsum is applied. Considerable gypsum occurs naturally in the soils of the Delta Area, but the amount and distribution within the soil profile are highly variable. Gypsum combined with leaching with 4 feet of water was included as one of the treatments in this experiment.

Infiltration measurements were made at each of the three sites. The average rates of infiltration for the plots receiving the heavy leaching treatment of 4 feet of water with and without gypsum are given in table 2. Rates were relatively high at all three sites at the time

Table 2. Infiltration rates† on plots receiving 4 feet of water with and without gypsum

1	2	3	4
Site	Treatment	Initial infiltration rate	Infiltration rate after 48 hours
	feet of water	*in./hr.*	*in./hr.*
A	4	1.9	0.27
A	4 + gypsum	2.9	0.21
C	4	1.6	0.35
C	4 + gypsum	1.2	0.30
D	4	4.2	0.33*
D	4 + gypsum	6.3	0.57*

* Least significant difference = 0.24
† Averages of 4 replicates

water was applied, but decreased rather rapidly, reaching somewhat constant values after from 24 to 48 hours. Usually, the terminal rate was maintained for the remainder of the leaching period.

As shown in the last column of table 2, there was no significant difference between rates for the plots with and without the addition of gypsum at sites A and C. However, a comparison of infiltration rates with ground-water levels shows that infiltration was limited by the drainage or ground-water conditions at these two sites rather than by the permeability of the soil. Dependence of infiltration rates upon free lateral movement of ground water from the plot area was illustrated during the leaching at site A when flow in the adjacent open drain was shut off for repair work downstream and drainage became temporarily restricted. This caused a rapid rise of the water table to within about one foot of the soil surface in the plot area and a marked reduction in infiltration rates. Leaching was, therefore, discontinued about a week until the drain was reopened and the water table had subsided. Resumption of leaching was accompanied by an appreciable increase in infiltration rates. Observations made at site C during leaching indicated that infiltration rates were also limited by drainage. Because of limiting drainage conditions, no significance can be attributed to infiltration rates as a measure of the effect of gypsum at sites A and C. Even if drainage had not been limiting, it is unlikely that the addition of 5 tons of gypsum per acre would have improved infiltration rates because, as shown in table 5, the gypsum naturally present in the surface foot of these soils was more than sufficient for reclamation purposes.

At site D, the drainage conditions were somewhat better than at sites A and C because the adjacent open drain was from 1 to 2 feet deeper and the water table in the plot area was considerably lower. Infiltration rates, therefore, were probably not limited by inadequate drainage conditions at this site. The average infiltration rate for the gypsum plots was 0.57 inches per hour as compared to 0.33 inches per hour for the no-gypsum plots. This difference is significant and is probably related to the fact that this soil naturally contains little gypsum in the surface (2 tons or less per acre-foot). Although there is a significant improvement in infiltration rates where gypsum is applied, the rates for the no-gypsum plots are sufficiently high for satisfactory leaching.

Infiltration rates depend somewhat on the quality of water. Use of high-quality, non-saline water for leaching alkali soils may result in decreased rates of infiltration. At Delta, the fairly saline water of the Sevier River, which contains a large proportion of calcium and magnesium, constitutes the sole irrigation water supply. This water is perhaps quite ideal for leaching Delta Area soils. Any major change in the quality of the irrigation water would no doubt result in a change in the infiltration characteristics of the soil.

Drainage Conditions

Drainage conditions are an important consideration in leaching the saline soils of the Delta Area, especially where large acreages are involved. In order for leaching to be effective, reasonably adequate drainage must be available. If drainage is restricted, leaching may raise the water table and its subsidence may be so delayed that waterlogging results and salinity conditions are greatly aggravated. The experimental leaching basins at each of the three sites were located near deep open drains in order to assure reasonably adequate drainage. Differences in leaching because of drainage conditions were thereby minimized.

Piezometers consisting of ⅜ inch iron pipes were installed to measure the position of the water table and the hydraulic head at points in the vicinity of the open drains. The principal installations were made on lines at right angles to the open drains and adjacent to the leaching plots. At site A, two lines were installed, one on the east side of the plots extending for a distance of 1500 feet north of the drain, and one on the west side extending 500 feet north. At sites C and D, one line of piezometers was installed at right angles to the drain on the east side of the plots, extending a distance of 500 feet to the south of the drains. The fluctuations of the water table near the leaching sites and changes in the water levels in the nearby open drains are shown in figure 6. The upper curve (solid line) represents the water level in the piezometer nearest to the leaching plots in each instance and the lower curve (dash line), the water level in the drain. The depth to water table is given in feet below the soil surface at the plots. The water levels in the open drains are also referred to this same datum.

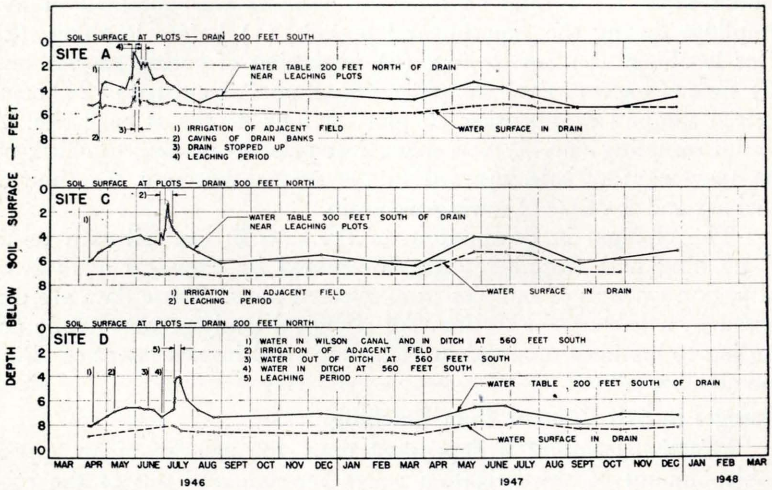

Fig. 6. Water table levels showing changes during the leaching and cropping periods at sites A, C, and D

In general, the seasonal variations of the ground-water levels are similar at the three sites. The water table begins to rise in April, reaching a peak in May or June, and lowers to a minimum about September. The period of high ground water corresponds to the irrigation period in the area. Water is usually turned into the canals in April and out in September. There is a slight rise in water levels at the three sites from September to December, followed by a gradual lowering until a minimum is reached in March. Owing to the leaching operations during the period June to August 1946, the water-table levels near the plots showed a rapid rise, then a gradual fall for a period of about 1 to 1½ months following the leaching.

A comparison of the water-table depths at the three sites shows that drainage conditions are considerably better at site D than at sites A and C. At site A, the yearly fluctuation of the water table was from 3½ feet to 5½ feet below the soil surface; at site C, from 4 to 6½ feet; and at site D, from 6½ to 8 feet.

Effectiveness of Leaching

The effectiveness of the leaching treatments was appraised by two methods: (1) periodic soil salinity determinations and (2) crop responses.

The changes in salt content that occurred during the leaching and cropping regime were determined by electrical conductivity measurements of 1:1 soil-water extracts, the data for which are given in appendix table 1. A total of 1008 soil samples was obtained in five samplings during the experimental period: (1) before leaching, (2) after leaching, (3) pre-sowing, (4) beginning of spring growth and (5) time of harvest. Each sampling, except no. 3, consisted of 240 composited samples representing 20 plots at four depths at each site. A partial sampling (no. 3) was made just prior to seeding to check on the movement of salts upward to the surface between the time of leaching and the time of sowing the grain.

The changes in composition of the salts in the soil as a result of leaching and cropping were determined by chemical analysis of saturation extracts of samples from selected plots. These data are discussed in a subsequent section. All chemical analyses were made according to methods reported in "Diagnosis and improvement of saline and alkali soils" (31).

Changes in Salt Content from Leaching

Effective leaching is dependent upon the passage of an appreciable amount of the irrigation water through and out of the root zone. For most field crops the root zone may be regarded as the first three feet of soil. The amount of water passing beyond the root zone for a given water application may be estimated from the moisture data, given in appendix table 3. Using the average of all values for available-water capacity for site A, it is evident that this soil retains approximately 3.1, 3.0, and 2.8 inches of water in the first, second and third feet of soil. Thus, if one foot of water is applied, only about 3.1 inches passes beyond the third foot. This gives limited removal of salt from the root zone. Correspondingly, from the two- and four-foot water applications approximately 15.1 inches and 39.1 inches of water, respectively, pass downward beyond the third foot of the soil.[3]

The effectiveness of the leaching treatments in removing salts from the soil is shown in figures 7, 8, and 9 for sites A, C, and D, res-

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[3]In this example, it is assumed that the moisture content of the soil was at the wilting percentage at the time leaching began. The amount of water retained by the soil, therefore, is equal to the difference in moisture content of the soil at the wilting point and that at field capacity. If the moisture content of the soil was above the wilting point at time of leaching, then the amount of water passing the root zone would be greater than the amounts indicated above.

pectively. The salt distribution before leaching was similar for sites A and C, the former having a somewhat higher salt content at all

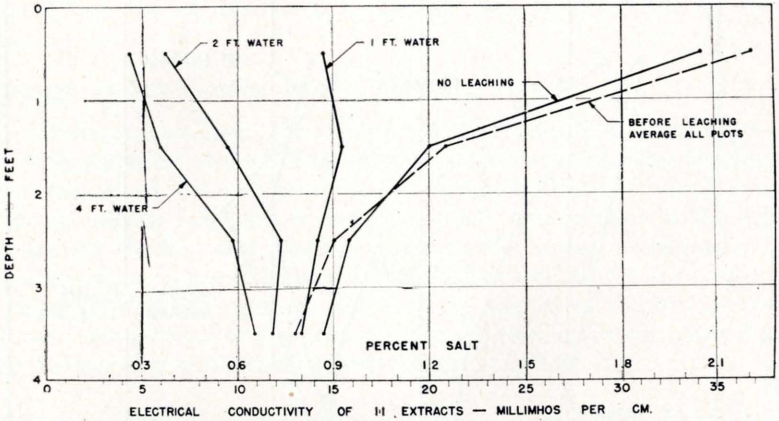

Fig. 7. Salt distribution in soil profile before and after leaching at site A showing effect of three leaching treatments.

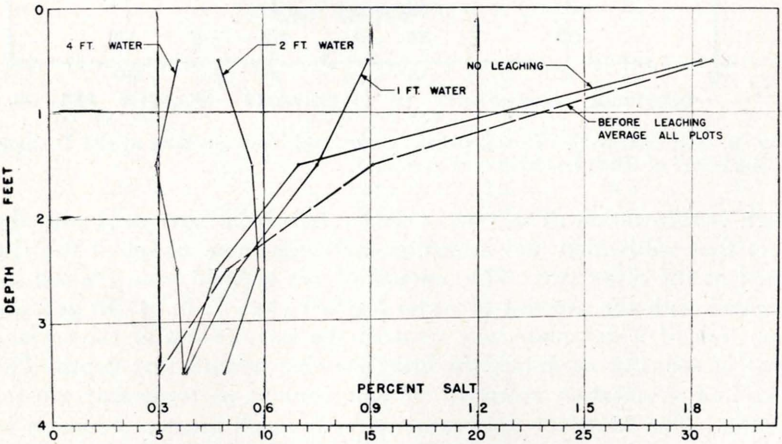

Fig. 8. Salt distribution in soil profile before and after leaching at site C showing effect of three leaching treatments

levels throughout the four-foot profile. This distribution of salt is typical of lands that have remained idle for a long time where a saline water table is present at a shallow depth. The concentration of salts at the surface is attributed to the upward movement, evaporation, and transpiration of the highly saline ground water. The salt distribution curve at site D prior to leaching (fig. 9) does not show an exceptionally

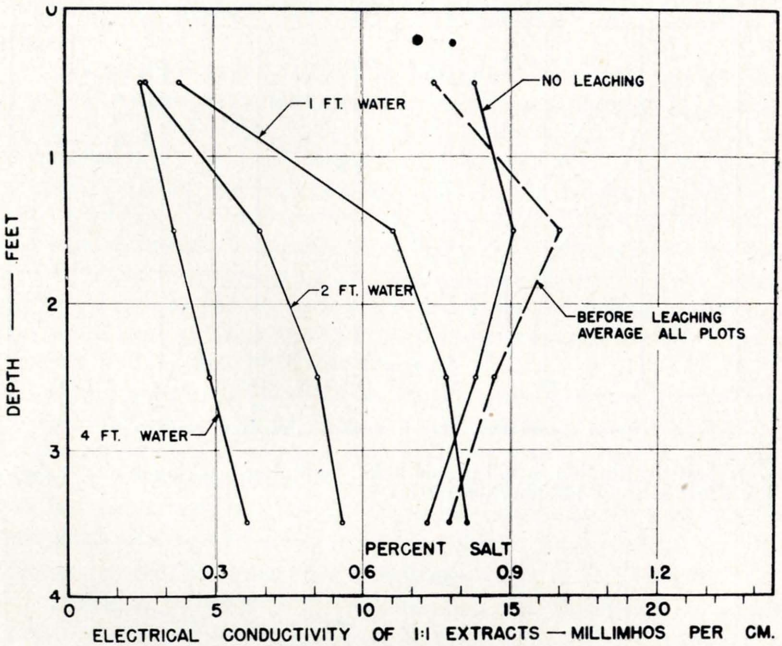

Fig. 9. Salt distribution in soil profile before and after leaching at site D showing effect of three leaching treatments

high concentration at the soil surface. This is in agreement with the fact that cultivation and irrigation had been more recent at this site than at the other two. The amount of salt leached from the soil increased with the amount of water applied (figs. 7, 8, 9). In general, one foot of water materially reduced the salt content of the surface foot of soil, but accomplished little leaching beyond that depth. The two-foot application reduced the salt content at somewhat greater depths. The four-foot application gave a much greater reduction in salt content throughout the entire root zone. At site C there was a slight increase of salt in the fourth foot for all treatments, which is probably related to the initially low salt content at this depth.

It should be noted that the leaching operation involved continuous or nearly continuous water application by ponding. Except for the one-foot treatment, a large part of the water applied passed through the root zone. It is common practice in many areas to attempt to reclaim salted soils by using frequent normal irrigations with or without crops being grown. Where this is done, leaching may be ineffective since much of the water applied is used by the crop or is evaporated from the soil surface and relatively little passes beyond the root zone.

Changes in Salt Content During Cropping Period

Following leaching, the salinity status of the soil was determined at four different times. The changes that occurred after leaching were caused, on the one hand, by the combined effects of winter rainfall and normal irrigation of the crop, which tended to carry the salts to greater depths; and, on the other hand, by the evaporation of moisture from the soil surface and transpiration by the crop, which tended to move salt upward. The average salinity of the surface foot of soil (conductivity of 1:1 extracts) for the five samplings made during the leaching and cropping period is given in table 3.

Table 3. Salinity status of leaching plots (0 to 1-foot depth) at sites A, C, and D for various sampling dates

1	2	3	4	5	6	7
		Electrical conductivity of 1:1 extract ($EC_1 \times 10^3$)				
Site	Treatment	Before leaching 1946	After leaching 1946	Pre-sowing 9/46	Spring 3/47	Harvest 7/47
	feet of water		*millimhos/cm*			
A	0	36.8*	34.2	40.1	22.1	21.7
	1	38.9	14.6	17.7	11.1	10.1
	2	33.7	6.4	8.6	6.2	7.7
	4	38.8	4.4	3.5	4.1	4.6
C	0	30.3	30.4	35.2	16.7	16.0
	1	28.9	14.9	16.4	8.5	8.8
	2	31.5	7.9	9.1	7.2	8.6
	4	31.2	5.3	2.9	4.7	5.7
D	0	12.6	13.8	13.2	2.3	2.7
	1	12.7	3.9	3.4	1.9	2.7
	2	12.1	2.8	4.4	1.3	2.3
	4	13.0	2.6	1.9	1.3	2.4

*All values are averages of four replicates except for pre-sowing sampling the values of which are averages of two replicates.

Generally, there was little difference in the salt content of the first foot of soil at sites A and C immediately after leaching and at the time of harvest (columns 4 and 7) for the higher leaching treatments. There were, however, slight increases in salt between the time of leaching and time of planting (columns 4 and 5) but this occurred only on the plots receiving 2 feet or less of water. In contrast, the plots at those sites which received the 4-foot leaching treatments showed either no change or a slight decrease in salt during the same period. Between September and March, a combination of one irrigation at time of seeding and several winter rains further reduced the salinity of the plots receiving the 0-, 1-, and 2-foot leaching treatments where the salt content was still fairly high (columns 5 and 6). From March to July there was a slight increase in salinity on all 2- and 4-foot plots even though two 6-inch irrigations were applied in May and June. In general, over the period from leaching (column 4) to harvest (column 7) it is evident that the 4-foot water application was the most effective treatment since there was little change in the salinity of the surface soil during this period. Changes in the surface soil resulting from leaching, winter rains, and irrigation are shown graphically in figure 10. This figure also shows changes at the 2-, 3-, and 4-foot depths.

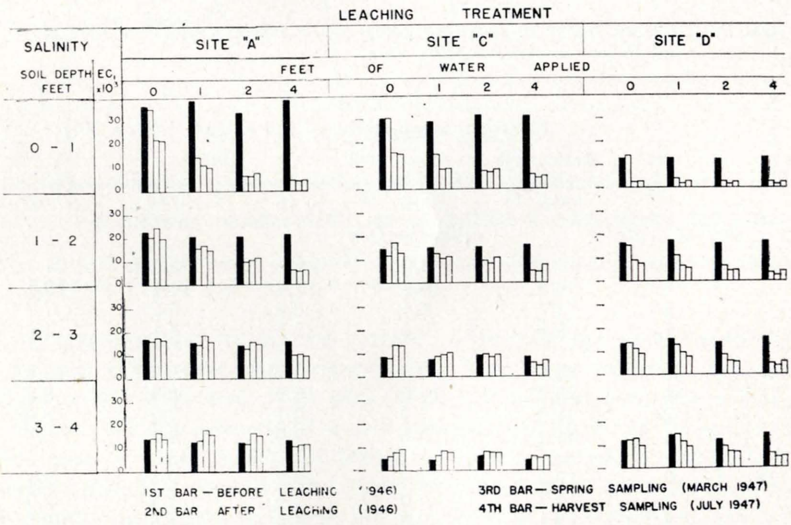

Fig. 10. Effect of leaching, winter rainfall, and normal irrigation on the salinity status of the soil at four depths on four sampling dates

Chemical Changes Resulting from Reclamation Treatments

In order to determine the chemical changes that resulted from the leaching treatments, and those that occurred owing to the subsequent irrigation and cropping regime, chemical analyses were made of samples from selected plots taken at three different periods: before leaching, after leaching, and at time of harvest. These analyses include the following determinations: pH of the saturated soil paste,

Table 4. Concentration and composition of salts in Delta soils before and after leaching with four feet of water.

1	2	3	4	5	6	7	8	9	10	11	12	13
Location					Soluble ions							
					Cations			Anions				
Site	Plot	Soil depth	Before or after leaching	Electrical conductivity sat. extract	Ca	Mg	Na	HCO^{3}	Cl	SO^{4}	Soluble sodium	Soluble salts
		feet		*millimhos/cm*	*m.e./l.*	*m.e./l.*	*m.e./l.*	*m.e./l.*	*m.e./l.*	*m.e./l.*	*percent*	*percent*
A	5	0-1	Before	76.6	90	218	694	5	880	112	69	2.44
			After	9.4	31	29	59	8	36	79	50	.33
		1-2	Before	38.2	56	73	307	2	345	93	70	1.56
			After	9.6	24	17	89	6	38	84	70	.50
C	10	0-1	Before	60.5	69	193	527	4	650	114	68	2.00
			After	12.1	32	38	76	4	62	83	52	.42
		1-2	Before	20.1	30	44	161	3	125	105	69	.71
			After	9.8	26	23	71	3	33	87	59	.37
D	19	0-1	Before	21.6	67	58	109	2	202	31	46	.76
			After	3.0	6	5	18	4	13	14	58	.12
		1-2	Before	28.1	80	81	159	3	270	50	49	1.08
			After	5.6	24	9	33	3	10	57	50	.28

Table 5. Chemical composition of the soil on three sampling dates for the two- and four-foot leaching treatments

Location		Soil depth (ft.)	Treatment (ft. water applied)	pH			Gypsum (tons/acre ft.)			Exchangeable-sodium-percent		
Site	Plot			Before leaching	After leaching	Harvest	Before leaching	After leaching	Harvest	Before leaching	After leaching	Harvest
A	7	1	2	7.80	7.85	7.90	6.4	1.0	1.5	26	17	13
		2		7.90	7.80	7.90	4.3	2.8	1.7	28	23	23
A	5	1	4	7.90	8.00	7.80	12.9	3.8	1.4	40	15	14
		2		8.05	7.90	8.00	10.3	1.9	1.9	36	24	23
A	4	1	4+gypsum	8.10	7.85	7.90	23.4	13.4	10.7	37	12	15
		2	(5 T/A)	8.05	8.00	8.00	9.3	4.1	3.8	24	23	22
C	12	1	2	7.90	7.70	7.80	17.4	7.6	6.9	34	22	16
		2		8.00	7.70	7.90	7.2	1.5	4.0	29	23	17
C	10	1	4	7.95	7.80	7.80	11.9	6.9	0.7	31	16	14
		2		8.05	7.80	7.80	10.3	2.8	2.2	41	16	15
D	19	1	4	7.60	8.00	....	2.4	0.9	....	11	7	....
		2		7.50	7.80	....	8.9	1.5	....	10	10	....
D	4	1	4+gypsum	7.50	7.80	....	2.1	4.1	....	16	6	....
		2	(5 T/A)	7.50	7.75	....	13.0	4.6	....	16	11	....

electrical conductivity of the saturation extract, soluble ions in the saturation extract (Ca, Mg, Na; HCO, C1–, SO==), ammonium acetate, extractable sodium and sulfates, and cation exchange capacity. All determinations were made according to methods recommended by the Salinity Laboratory (31). From these analyses the gypsum content of the soil, the exchangeable-sodium-percentage and the soluble-sodium-percentage were calculated. These data are given in detail in appendix table 2, and are shown in part in tables 4 and 5.

Analyses of the saturation extracts show that the soluble salts present in the Delta soils are largely chlorides and sulfates of sodium, calcium, and magnesium with sodium salts predominating (table 4). Carbonates are absent and only small quantities of bicarbonates are present. Where salts are high as in the surface foot at sites A and C, sodium salts, chiefly sodium chloride, make up 65 to 81 percent of the total salts present for all plots studied (appendix table 2). At site D, however, where salt is less abundant in the surface soil than at the other sites, sodium salts are less predominant being somewhat less than 50 percent of the total. In this respect the composition of the salts at site D before leaching more nearly reflects that at sites A and C after the soil was leached, which is a further indication that irrigation had been more recent at site D than at the other two sites.

As indicated in table 4, heavy leaching with four feet of water reduced the percentage of soluble sodium in the surface foot of soil from 69 to 50 on plot 5, site A, and from 68 to 52 on plot 10, site C. However, on plot 19, site D, the percentage of sodium salts in the surface foot actually increased after leaching. This was the only case where an increase in sodium was noted. Changes in salt composition in the second foot of the profile were somewhat variable, but in the two- to four-foot zone there was little or no change regardless of the amount of leaching.

The Delta soils have favorable pH values as shown in table 5, and appendix table 2. Prior to leaching they ranged from 7.50 to 8.10 in the surface foot at the three sites. The subsoil pH was as low as 7.40 in a few cases, such as plot 4, site D, but in no instance did it exceed 8.25, the maximum found for the surface soil. For any single plot, however, there were no significant changes in pH resulting from the leaching treatments. This point is of particular interest since many western soils, which like the Delta soils are high both in soluble salts and exchangeable sodium, have higher pH values when the salts are removed by leaching. In such cases, the increase in pH following leaching results from the removal of the excess salts and the resulting hydrolysis of the exchangeable sodium. Failure of the Delta soils to have higher pH values when leached results from the appreciable amounts of gypsum found in them (table 5 and appendix table 2). This suggests that the presence of gypsum in soils containing a high percentage of exchangeable sodium may preclude the use of pH as a criterion for distinguishing alkali from non-alkali soils.

Sevier River water contains large amounts of sulfate ions (table 1) and it is to be expected that calcium sulfate (gypsum) will precipitate when the soil solution becomes concentrated by evaporation and transpiration. Since gypsum greatly facilitates the reclamation of alkali soils by replacing harmful exchangeable sodium with calcium, the amount present in the soil is of considerable importance. As shown in table 5, the soils at the three experimental sites contain considerable quantities of gypsum within the root zone with the largest amounts at or near the surface. Where land has been abandoned for a long time, such as at sites A and C, much more gypsum is found in the surface foot of soil than at greater depths. However, under conditions of frequent irrigation, or where land has been idle for only a short time, such as at site D, the highest gypsum content usually occurs in the second foot of soil. The applications of two and four feet of water for leaching purposes greatly reduced the gypsum content of the first and second foot of soil on all plots studied. Soils with high gypsum content in the surface, as at sites A and C, should not require the addition of this amendment for reclamation. The need for soil testing to determine the presence or absence of gypsum prior to the beginning of a reclamation program is emphasized.

Most western soils contain some adsorbed sodium in the exchange-complex of the clay colloids. If the exchangeable-sodium-percentage exceeds 15, then the soil is classified as alkali (31). When it appreciably exceeds this value, the soil is in need of chemical amendment in addition to leaching to bring about reclamation except when appreciable quantities of gypsum are present in the surface soil. At sites A and C, the exchangeable-sodium-percentage in the first foot of soil before leaching ranged from 26 to 40 and decreased somewhat with depth (table 5 and appendix table 2). The analytical data show that these are saline-alkali soils (31) and contain sufficient gypsum for reclamation.

The effect of gypsum in facilitating reclamation of Delta Area soils as measured by the reduction in the exchangeable-sodium-percentage during leaching is illustrated by the data in table 5. Plot 5, site A, prior to leaching contained approximately 13 tons of gypsum per acre-foot in the surface. Leaching with 4 feet of water reduced the exchangeable-sodium-percentage from 40 to 15 in the first foot and from 36 to 24 in the second foot. There was a smaller reduction in the third foot of the profile. Plot 4 at site A contained 23.4 tons per acre-foot of gypsum in the surface and in addition received a 5-ton per acre application making a total of 28.4 tons. Heavy leaching reduced the

Fig. 11. Condition of the wheat crop at site A at the time of harvest. In addition to the leaching treatment indicated, all plots received 1½ to 2 feet of irrigation water. The weed growth on the check and 1-foot plots is *Bassia hyssopifolia*

Fig. 12. Condition of the wheat crop at site C at the time of harvest. In addition to the leaching treatment indicated, all plots received 1½ to 2 feet of irrigation water. The weed growth on the check and 1-foot plots is *Bassia hyssopifolia*

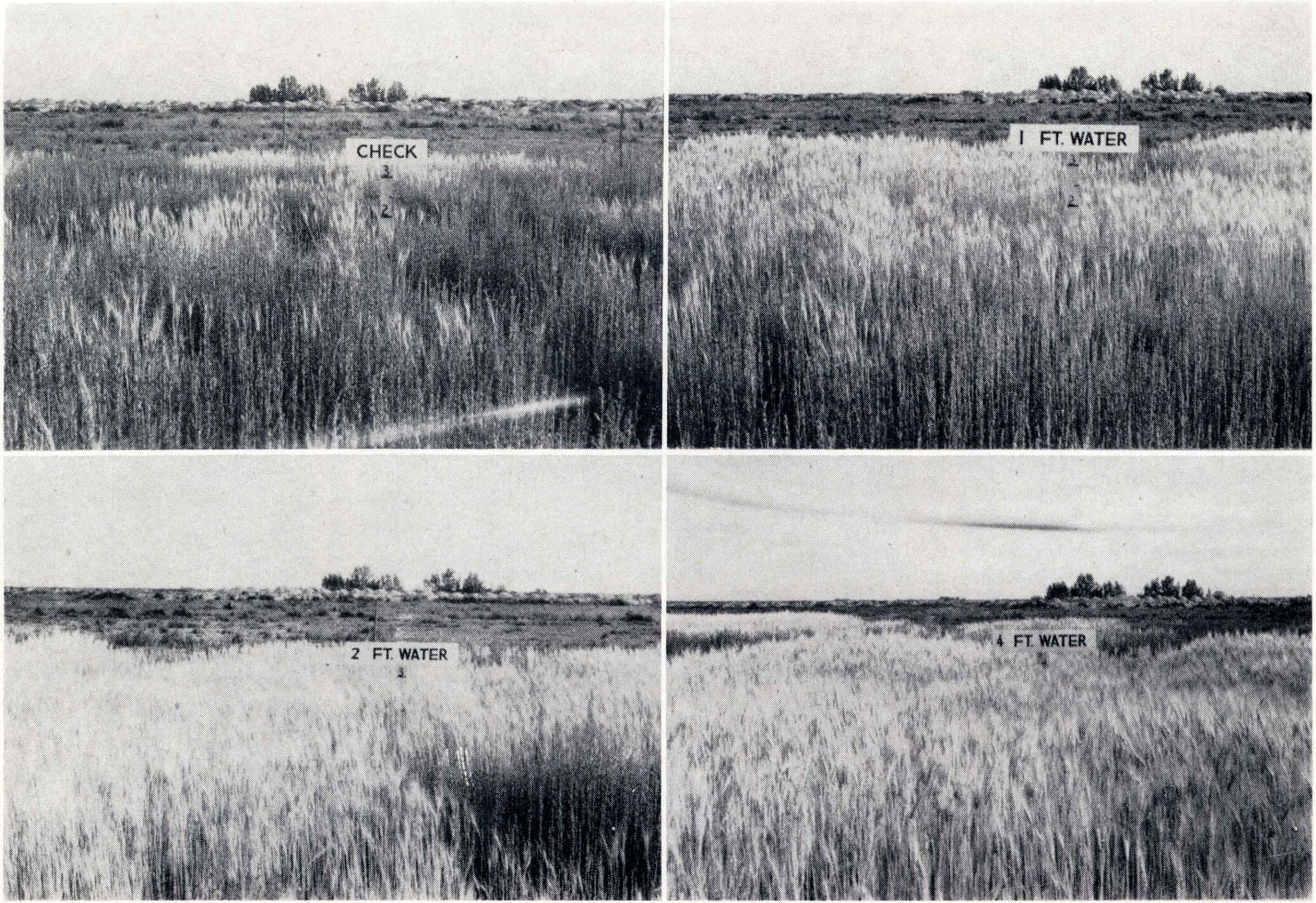

Fig. 13. Condition of the wheat crop at site D at the time of harvest. In addition to the leaching treatment indicated, all plots received $1\frac{1}{2}$ to 2 feet of irrigation water

exchangeable-sodium-percentage from 37 to 12. The resulting lower exchangeable-sodium-percentage on plot 4 as compared to plot 5 is undoubtedly the result of the combined effects of both native and applied gypsum. On plot 10, site C, containing 12 tons per acre-foot of gypsum, the same leaching treatment reduced the exchangeable-sodium-percentage from 31 to 16 in the first foot of soil and from 41 to 16 in the second foot with little or no reduction at greater depths. The two-foot leaching treatment was somewhat less effective than the four-foot treatment in reducing the exchangeable-sodium-percentage of the soils at these two sites.

The soil at site D contains on the average about two tons of gypsum in the surface foot with somewhat more in the second and third foot depths. On plot 19, the exchangeable-sodium-percentage was reduced by the four-foot leaching treatment in only the surface foot, but on plot 4, where an additional five tons of gypsum were added per acre, the exchangeable-sodium-percentage was reduced appreciably in the first three feet of the soil profile. Even though the added gypsum proved effective in reducing adsorbed sodium at site D, this soil is a borderline case of an alkali soil and the benefits from added gypsum to reduce exchangeable sodium further would not likely be economic.

Crop Response

Fall wheat was grown on the experimental sites to serve as a measure of the effectiveness of leaching and to determine the relationship between crop yields and salinity. The grain at the time of harvest at sites A, C, and D is shown in figures 11, 12 and 13, respectively. The depths of water shown in the figures indicate the initial leaching treatments. Grain height in feet is indicated by the stake. In general, the growth varies directly with the amount of leaching water applied. In addition to the leaching treatments, all of the plots received three irrigations of 6 to 8 inches each plus 12 inches of rain between the time of planting and harvest. The total amount of water received by the plots was therefore from 2½ to 3 feet more than the initial leaching application. The four-foot leaching treatments gave the most luxuriant growth and highest yields in all cases. The vegetation on the plots receiving no leaching and one foot of water at sites A and C was largely weeds (*Bassia hyssopifolia*).

The relative height and yields of the grain at time of harvest for the various treatments at each of the three sites are shown in figure 14. Each bundle, except those for the no-treatment plots at sites A and C, contains the grain harvested from five one-yard square quadrates, 45 square feet, from one plot. The no-treatment bundles at sites A and C contain the grain from an entire plot or 1200 square feet. A comparative bundle for these two plots would, therefore, contain about 1/27 of the amount shown. Average yields for the five leaching treat-

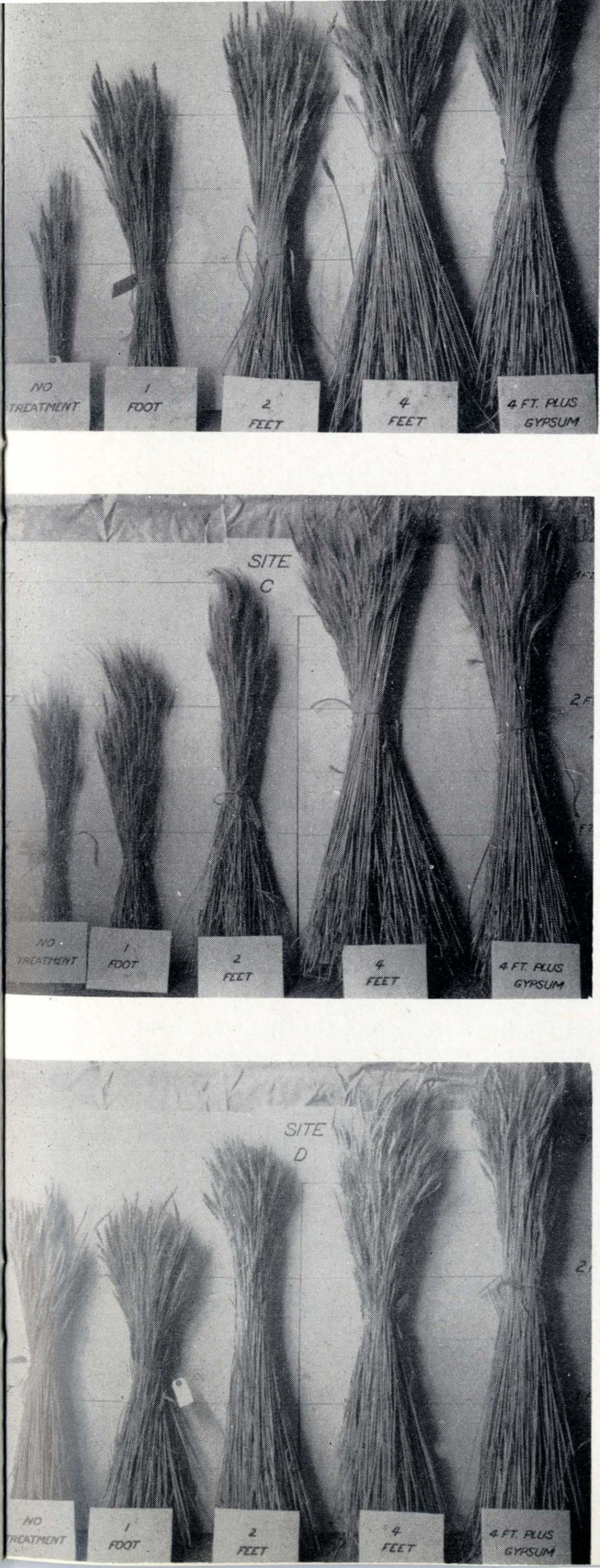

Fig. 14. Grain samples harvested from plots at sites A, C, and D showing differences as a result of leaching treatments. The samples shown for the no-treatment plots at sites A and C should be reduced by 1/27th to be comparable to other samples

ments in bushels of wheat and tons of straw per acre together with least significant differences between treatments are presented in table 6. Individual plot yields together with salinity and test weight values are given in appendix table 4. There were increases in yields with in-

Table 6. Average yields of wheat and straw at sites A, C, and D in relation to leaching treatments*

1	2	3	4	5	6	7
Site	Leaching treatment - feet of water applied					Least significant difference
	0	1	2	4	4+*gypsum*	
			bushels wheat per acre			
A	0.7	13.6	23.4	42.6	37.8	7.9
C	5.2	23.7	31.3	43.1	37.8	9.6
D	28.7	25.9	33.8	41.1	41.1	7.4
			tons straw per acre			
A	0.05	0.96	1.58	3.33	2.94	0.81
C	0.40	1.64	2.45	4.14	4.22	1.45
D	1.97	1.79	2.51	3.42	3.61	1.10

* Averages of four replicates.

crease in leaching water at all three sites. However, the differences are more pronounced at sites A and C than at site D. Significant increases occurred for all leaching treatments at sites A and C whereas only the 4-foot leaching shows significance at site D. Highest yields were obtained with 4 feet of water at all three sites. In comparing the results for the 4-foot leaching treatments with and without gypsum amendment it is to be noted that at sites A and C the average yields are somewhat lower where gypsum was applied. These differences, however, are not statistically significant.

The quality of the wheat produced at each of the sites was about the same, but appreciable differences resulted from the various treatments. Test weights in pounds per bushel (appendix table 4) ranged from 59.0 to 63.0 at site A with but one exception, from 61.5 to 63.0 at site C, and from 60.0 to 63.7 at site D. In general, high test weight is associated with low salinity. The wheat kernels showed considerable shrinkage at the high salinity levels whereas the kernels from the low salinity plots were full and firm.

The relation between the average yield and the amount of water used for leaching is shown graphically in figure 15. This relation is approximately linear at each of the three sites and may be expressed by the equation:

$$Y = m(W) + b$$

Where Y = yield in bushels per acre

W = depth of water applied in feet (initial leaching treatment)

m = the increase in yield (bu/A) per foot of water applied

b = the yield (bu/A) obtained with no initial leaching but with normal irrigation.

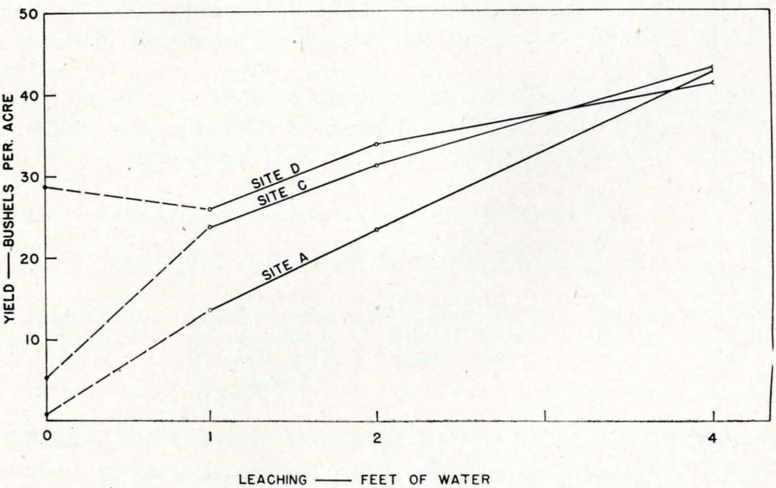

Fig. 15. Relation of grain yields to amount of water used for leaching

The values of *m* and *b* for the best fit straight line using the method of least squares for each of the three soil types, sites A, C, and D, are:

Site	*Soil type*	*m*	*b*
A	Woodrow clay loam	10.2	2.1
C	Oasis silty clay loam	8.8	10.2
D	Gordon clay	4.7	24.0

This equation holds for values of W from 0 to 4 since 4 feet of water is the maximum initial leaching treatment used in the experiment. However, inspection of figure 15 suggests that additional leaching would have resulted in even greater yields. The constant *b* is the average yield in bushels per acre that may be expected at these locations where normal irrigations are applied with no initial leaching. If initial leaching is practiced, as was the case in this experiment, the yield increases at the rate of *m* bushels per acre for each foot of water applied for leaching purposes. For example, if the soil at site A were leached initially with 3 feet of water, the total yield to be expected would be $2.1 + 3\ (10.2) = 32.7$ bushels per acre.

Although there is a definite relation between wheat yields and leaching as shown in figure 15, it must be kept in mind that yields are related to the amount of water applied for leaching only to the extent to which salt is removed from the root zone. The effect of soil salinity upon grain yields is shown in figure 16.

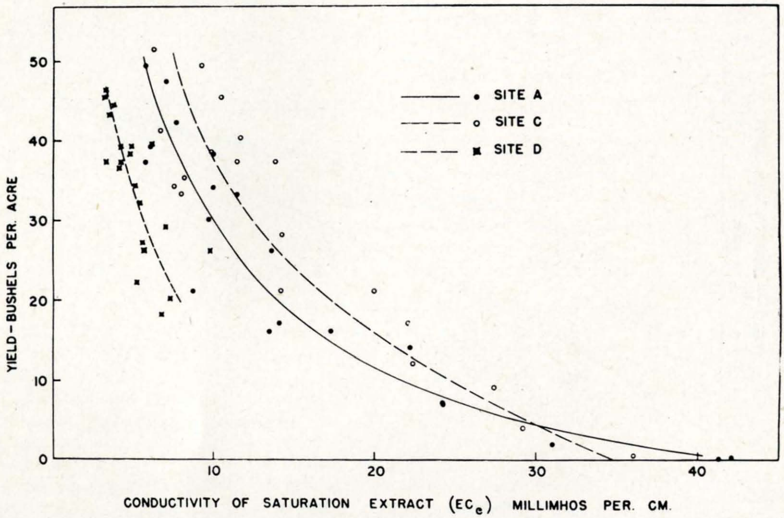

Fig. 16. Relation of grain yields to average salinity in the surface two feet of soil

Yields in bushels per acre are plotted against the conductivity of the saturation extract[4] in millimhos per centimeter and approximate curves are shown for each site. Conductivity values are averages of the first and second foot of soil at the beginning of the growing period, March 1947, and at the time of harvest, July 1947, and thus represent the salinity status of the root zone for the period during which the

[4]Soil salinity when expressed as conductivity of the saturation extract is more closely related to crop growth than when expressed on a weight basis such as percent salt, or conductivity of 1:1 soil: water extracts (31). Crops are responsive to the concentration of the soil solution which in turn is related to the moisture retention characteristics of the soil. Two soils, for example, may have equal soluble salt content expressed as percent, dry weight basis, but the concentration of the soil solutions at comparable field moisture levels, such as field capacity or wilting percentage, may be 8 to 10 times higher for a sandy loam than for clay soil. The conductivity of the saturation extract relates the concentration of the soil solution to the field moisture range and thereby makes the salinity appraisal easier to interpret in terms of crop response. See the appendix, page 43, for the method of converting from conductivity of 1:1 soil: water extracts to conductivity of the saturation extract.

crop was grown. These salinity values, together with wheat yields and test weights, are given in appendix table 4. From the curves shown in figure 16, it is evident that salinity has a marked effect upon yield, especially at the low salinity levels. The curves are of hyperbolic character becoming very steep at the low salt levels and flattening out as salinity increases.

Slight increases in salt content, where salinity is low, result in greatly reduced wheat yields. It is apparent, therefore, that in order to maintain maximum yields, the salt content of the soil must be kept low.

As an aid in evaluating the effect of soil salinity on crop growth, the salinity scale proposed by Scofield (25) and modified by Richards, et al (31) is reproduced in table 7. According to this scale, a conductivity of 4 millimhos per centimeter is regarded as an approximate boundary between a non-saline and saline soil. In all cases in this experiment, except in the heavy leaching treatments at site D (appendix table 4) the conductivity of the saturation extract for the first two feet of soil exceeds 4 millimhos per centimeter. According to this classification, therefore, the soils at the three experimental sites are for the most part saline even after leaching with 4 feet of water.

Table 7. Scale showing the relation of salinity to crop growth

Conductivity of the saturation extract in millimhos/cm			
0	4	8	15
All crops thrive. No evidence of salt injury	Sensitive crops do not thrive. Tolerant crops may do well	Crop growth restricted. Yields usually poor	Only a few species survive

Feasibility of Leaching

In considering leaching as a practical means of reclaiming saline and alkali soils of this and other areas, the economic aspects in addition to the physical factors related to reclamation must be taken into account. Adequacy of drainage, availability of irrigation water, cost of leaching, and cash returns resulting from reclamation are among the major factors to be considered.

The results from this two-year study in the Delta Area show that it is possible to leach the excess salts from these soils with large applications of water where adequate drainage is provided. This possibility depends largely upon the unrestricted movement of water down through the soil and out into the drainage ways. Without adequate drainage, attempted leaching may be detrimental rather than beneficial.

In an over-all leaching program, the availability of irrigation water for leaching purposes is an important consideration. It may be possible to leach during years of better than normal water supply and still furnish irrigation water to the present irrigated acreage. If it is assumed that water supply is not a limiting factor and that it is possible to obtain adequate drainage, then the question of feasibility of leaching is largely one of economics.

The economics of leaching depends upon the initial cost and the price received for crops after the land has been reclaimed. Because of changing economic conditions, it is difficult to predict with certainty future crop prices and to estimate leaching costs. Therefore, an accurate evaluation of returns from leaching would require a comprehensive economic study, which is beyond the scope of this investigation. However, for purposes of illustration, an evaluation of the returns that may be expected as a result of leaching at the three sites studied is presented.

The net returns from leaching equal the increase in income resulting from leaching, minus the leaching costs. The increase in income resulting from leaching is the amount in excess of the returns received from the land under normal irrigation practice. This return is an annual one that will continue as long as the effect of leaching persists. The cost of leaching is a capital cost or lump sum payment made at the time the land is reclaimed. If adequate drainage is maintained and proper soil management is practiced, it is to be expected that the effect of leaching will be permanent. The following estimates on cost of leaching assume the use of the contour-border method, which has proved satisfactory in the Imperial Valley, California. Large closed basins are formed by constructing high borders along the contours to allow water to be ponded.

Item	*Estimated cost*
Water[5]	\$1.50 per acre-foot
Labor for leaching[6]	2.20 per acre-foot
Land preparation for leaching[7]	
(1) Engineering costs	2.50 per acre
(2) Construction of contour borders (18″ high)	5.00 per acre
Fertilizer to offset losses resulting from leaching[8]	5.00 per acre
Miscellaneous (waste outlets, gates, etc.)	1.00 per acre

[5]The market value of water at Delta has varied considerably over a period of years. For purposes of analysis, an average value of \$1.50 per acre-foot appears to be reasonable.

(*continued on next page*)

Based on the above estimates, the cost of leaching would be:

Leaching application	*Capital cost*	*Annual cost*[9]
1 ft. of water	\$17.20	\$2.12
2 ft. of water	20.90	2.58
4 ft. of water	28.30	3.49

The return from the land that may be attributed to leaching, which is the return in addition to that obtained with normal irrigation practices, may be derived from the equation of $Y = m(W) + b$ given on page 35. This equation is based upon the data of table 6. The value b is the yield in bushels per acre that was obtained with no initial leaching but where normal irrigations were applied. This value is dependent largely upon the initial salinity status of the soil. The value m is the increase in yield that resulted from the application of each foot of water in the initial leaching treatment. This value is independent of the initial salinity status of the soil (within the range encountered in this experiment), and may be considered as an index to the effectiveness of leaching. The values of m and b obtained at sites A, C, and D are given on page 35. A value of $m=O$ would indicate that leaching is ineffective and there is no increase in crop yields from leaching. A comparison of the values of m shows that leaching was most effective at site A with an increase of 10.2 bushels per acre per foot of water applied, and progressively less effective at sites C ($m = 8.8$) and D ($m = 4.7$), respectively.

The cash value of leaching as determined in this experiment using wheat as the farm crop is based upon the average price of wheat (\$1.03 per bushel) received by Utah farmers during the 32-year period from 1914 to 1945. The annual cash return over and above that received as a result of normal irrigation practice is equal to the unit price of

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[6]It is assumed that an average farm stream of 5 cfs can be cared for by one irrigator. At this rate of application the amount of water applied to the land is $5 \times 2 = 10$ acre-feet per 24 hours. At the current rate of \$0.85 per hour for labor, the cost of applying the water per acre-foot would be $0.85 \times 24/10 = \$2.20$.

[7]These costs are farmers' estimates obtained from leaching operations in the Imperial Valley, California, and are furnished by the Division of Irrigation, Soil Conservation Service.

[8]Leaching removes some plant nutrients principally nitrates from the soil in addition to soluble salts (9, 10). It is estimated that the fertilizer application required to offset losses resulting from leaching will not exceed 125 lbs. per acre. At the current price of \$80 per ton for a 16-20-0 fertilizer the cost would be \$5.00 per acre.

[9]Leaching costs are given on a yearly basis for comparison with the annual returns from leaching. Interest is taken at 4 percent per annum and it is assumed (for purposes of analysis only) that leaching is repeated every 10 years.

wheat, $1.03, times the yield resulting from leaching, m (W), in the above equation.

A summary of these returns for the one-, two-, and four-foot leaching treatments at each of the three experimental sites is given in table 8. The net annual cash returns after deducting the leaching costs are also given.

*Table 8. Annual returns per acre resulting from leaching**

Site and soil type	Water applied for leaching	Increased yields from leaching m(W)	Gross returns from leaching	Estimated leaching costs	Net returns from leaching
	ft.	*bushels/acre*	*dollars*	*dollars*	*dollars*
A	1	10.2	10.50	2.12	8.38
Woodrow	2	20.4	21.00	2.58	18.42
clay loam	4	40.8	42.00	3.49	38.51
C	1	8.8	9.06	2.12	6.94
Oasis silty	2	17.6	18.12	2.58	15.54
clay loam	4	35.2	36.24	3.49	32.75
D	1	4.7	4.84	2.12	2.72
Gordon clay	2	9.4	9.68	2.58	7.10
	4	18.8	19.36	3.49	15.87

*Based on wheat prices of $1.03 per bushel, average for 32 years (1914-1945)

It is evident from the data of table 8 that at these three experimental sites the cost of leaching is small compared to the cash returns that result. For example, the annual cash return at site A where the soil was leached with 4 feet of water, is about 12 times as great as the annual cost of leaching. The net annual returns where 1 foot of water was used for leaching range from $2.72 per acre at site D to $8.38 at site A. Where 4 feet of water was applied the net annual returns ranged from $15.87 to $38.51 per acre.

These experiments were conducted at locations where drainage was reasonably adequate, thereby making it possible to leach the salts from the soil effectively and obtain large increases in cash returns. Drainage is the primary problem in the Delta Area and in order to protect the productive lands, to improve production on lands of moderate salinity, and to reclaim the idle highly saline-alkali soils of the area, adequate drainage must be provided. If the net returns resulting from leaching with 4 feet of water, based upon a 32-year average price of wheat, were applied for drainage, these lands could support annual improvements of $15.87 to $38.51 per acre. This is equivalent to a capital investment of from $248 to $602 for each acre of land reclaimed, (assuming amortization of costs in 25 years at an interest rate of 4 percent per annum).

CONCLUSIONS

1. Drainage must be adequate in order for leaching to be effective. Attempted leaching without sufficient drainage may be detrimental rather than beneficial.
2. The soils at the three locations in the Delta Area are saline-alkali, having conductivities of the saturation extract greater than 4 millimhos per centimeter and exchangeable-sodium-percentages greater than 15. For complete reclamation the excess adsorbed sodium must be replaced by calcium and the excess soluble salts must be removed.
3. Gypsum is naturally present in these soils in quantities sufficient to supply the required calcium for reclamation. Amendments such as gypsum or sulfur are not required.
4. Leaching with 4 feet of water effectively reclaimed these saline-alkali soils.
5. Wheat yields increased directly with the amount of water applied for leaching purposes. The average rate of increase in yields at the three sites under study were 10.2, 8.8, and 4.7 bushels per acre for each 1-foot of leaching water applied.
6. Wheat yields varied inversely with the residual salinity of the soil after leaching. At high salt levels large reductions in salt content gave only slight improvement in yields whereas at low salinity levels small decreases in salt resulted in large increases in yield.

LITERATURE CITED

1. Burgess, P. S. Alkali soil studies and methods of reclamation. Ariz. Agr. Exp. Sta. Bul. 123. 1928.
2. Catlin, C. N. and Vinson, A. E. Treatment of black alkali with gypsum. Ariz. Agr. Exp. Sta. Bul. 102. 1925.
3. Curry, A. S. Saline soils and their management. N. Mex. Agr. Col. Ext. Ser. Cir. 105. 1939.
4. Dunnewald, T. J. Removal of alkali by drainage and leaching. Wyo. Agr. Exp. Sta. Bul. 276. 1946.
5. Fitts, J. W., Lyons, E. S., and Rhoades, H. F. Chemical treatment of "slick spots." Soil Sci. Soc. Amer. Proc. 8: 432-436. 1943.
6. Gapon, E. N. On the theory of exchange absorption in soils. Jour. Gen. Chem. (U.S.S.R.) 3: 144-163. 1933.
7. Geddes, J. A., Fredrickson, C. D. and Bergeson, E. C. Social conditions in the Delta Area, Utah. Utah Agr. Exp. Sta. Bul. 288. 1939.
8. Greaves, J. E. and Hirst, C. T. Composition of irrigation waters of the state. Utah Agr. Exp. Sta. Bul. 163. 1918.
9. ...., Stewart, R. and Hirst, C. T. Influence of crop, season, and water on the bacterial activities of the soil. Jour. Agr. Res. 9: 293-341. 1917.
10. ...., Hirst, C. T. and Lund, Yeppa. The leaching of alkali soil. Soil Sci. 16: 407-426. 1923.

11. Harris, F. S. Soil alkali, its origin, nature and treatment. New York, John Wiley and Sons, Inc., 1920. 258 p., illus.

12. Hayward, H. E. and Spurr, Winifred B. Effects of osmotic concentration of substrates on the entry of water into corn roots. Bot. Gaz. 105: 152-164. 1943.

13. ...., and Magistad, O. C. The salt problem in irrigation agriculture. U. S. Dept. Agr. Misc. pub. 607. 1946.

14. Hilgard, E. W. Soils. New York, The Macmillan Co., 1907.

15. Israelsen, O. W. Drainage and irrigation, soil, economic, and social conditions, Delta Area, Utah. Division 1, Drainage and irrigation conditions. Utah Agr. Exp. Sta. Bul. 255. 1935.

16. ...., and Reeve, R. C. Canal lining experiments in the Delta Area, Utah. Utah Agr. Exp. Sta. Bul. 313. 1944.

17. Jennings, D. S. and Peterson, J. D. Drainage and irrigation, soil, economic, and social conditions, Delta Area, Utah. Division 2, Soil conditions. Utah Agr. Exp. Sta. Bul. 256. 1935.

18. Kelley, W. P. and Brown, S. M. Base exchange in relation to alkali soils. Soil Sci. 20: 477-495. 1925.

19. ...., and Arany, A. The chemical effect of gypsum, sulfur, iron, sulfate, and alum on alkali soil. Hilgardia 3: 393-420. 1928.

20. .... The reclamation of alkali soils. Calif. Agr. Exp. Sta. Bul. 617. 1937.

21. ...., and Thomas, E. E. The reclamation of the Fresno type of black-alkali soil. Calif. Agr. Exp. Sta. Bul. 455. 1928.

22. Larson, C. A. Reclamation of saline (alkali) soil in the Yakima Valley, Washington. Wash. Agr. Exp. Sta. Bul. 376. 1939.

23. Magistad, O. C. and Christiansen, J. E. Saline soils, their nature and management. U. S. Dept. Agr. Cir. 707. 1944.

24. Reitemeier, R. F. Semimicroanalysis of saline soil solution. Ind. Eng. Chem., Anal. Ed. 15: 393-402. 1943.

25. Scofield, C. S. The Pecos River joint investigation, 1939-1940. Soil salinity investigations. U. S. Bur. Pl. Ind. 1941.

26. de Sigmond, A. A. J. Contribution to the theory of the origin of alkali soils. Soil Sci. 21: 455-475. 1926.

27. Snyder, R. S., Kulp, M. R., Baker, G. O. and Marr, J. C. Alkali reclamation investigations. Idaho Agr. Exp. Sta. Bul. 233. 1940.

28. Strahorn, A. T., Stucki, H., and Jennings, D. S. Soil survey of the Delta Area. U. S. Bur. Soils. 1922.

29. Thomas, E. E. Reclamation of white-alkali soils in the Imperial Valley. Calif. Agr. Exp. Sta. Bul. 601. 1936.

30. Thomas, W. P., and Blanch, G. T. Drainage and irrigation, soil, economic and social conditions. Delta Area, Utah. Division 3, Economic conditions. Utah Agr. Exp. Sta. Bul. 273. 1936.

31. U. S. Regional Salinity Laboratory. Diagnosis and improvement of saline and alkali soils. By Laboratory Staff, L. A. Richards, editor. 1947. multilithed, 157 p., illus.

32. Wursten, J. L. and Powers, W. L. Reclamation of virgin black-alkali soils. Amer. Soc. Agron. Jour. 26: 752-762. 1934.

APPENDIX

In this study numerous chemical and physical data were collected. Brief tables summarizing the data are included in the text and the detailed data are given in the appendix tables 1 to 4. Soil depths listed in these tables as 1, 2, 3, and 4 feet refer to the 0-1, 1-2, 2-3, and 3-4 foot horizons, respectively, of the soil profile. The semi-microchemical methods of Reitmeier (24) were used. These together with physical methods commonly used in the diagnosis of saline and alkali soils have subsequently been reported by the Salinity Laboratory (31). Specific reference to methods in the latter, which were used in this study are as follows:

		Method numbers
Salinity of 1:1 soil-water extracts EC_1		3 & 5c
Salinity of saturation-percentage extracts, ECe		3, 4 & 5a
pH of saturated soil paste		10a
Soluble ions:	Calcium	17
	Magnesium	18
	Sodium	19
	Bicarbonate	21
	Chloride	22
	Sulfate	23
Cation exchange capacity		16 I and II
Exchangeable sodium		16 I and 19
Gypsum		9a
Saturation-moisture percentage, SP		34a
One-third atmosphere moisture percentage		37
Fifteen-atmosphere moisture percentage		39

The symbol EC is used to represent electrical conductivity (31), the standard unit for which is mhos/cm. Since this is a large unit, most irrigation waters and soil solutions have conductivity values much less than unity. These are inconvenient for the purpose of expressing and comparing data. Therefore, the smaller subunit, millimhos per cm ($EC \times 10^3$), is used in expressing salinity data because it gives a more convenient location of the decimal point. $EC \times 10^5$ ($K \times 10^5$) has been used by the Rubidoux Laboratory and some other agencies. Micromhos/cm ($EC \times 10^6$) is the unit most commonly used throughout the world for expressing the conductivity of solutions. The relationship of these various units as applied to waters and soil extracts is illustrated as follows:

Sevier River water (see table 1, p. 8)

$EC = .00265$ mhos/cm

$EC \times 10^3 = 2.65$ (millimhos/cm)

$EC \times 10^5 = 2.65$ ($K \times 10^5$)

$EC \times 10^6 = 2650$ (micromhos/cm)

Soil-water extracts

$ECe \times 10^3 =$ Electrical conductivity (millimhos/cm of saturation extract)

$EC_1 \times 10^3 =$ Electrical conductivity (millimhos/cm of a 1:1 soil-water extract)

$EC_5 \times 10^3 =$ Electrical conductivity (millimhos/cm of a 1:5 soil-water extract)

For convenience, all routine salinity determinations were made by measuring the electrical conductivity of 1:1 soil-water extracts (EC_1). Plant growth is directly related to the salinity of the soil solution, but because of wide textural variations among soils, there is no general relationship between plant growth and the salinity of 1:1 extracts (EC_1). There is, however, a close relationship between plant growth and salinity of the saturation extract (ECe). It is desirable to relate values for EC_1 and ECe for purposes of interpretation.

Values for EC_1, ECe, and SP were obtained for one complete sampling of the leaching plots (240 samples taken in March 1947). These data were used to derive, by the method of successive approximations, the general equation given below which expresses the relationship between EC_1 and ECe and SP.

$$ECe = \frac{100\ EC_1 - 0.23\ (EC_1) - (4 - 0.067\ SP)}{SP}$$

Table 1. Electrical conductivity of 1:1 soil-water extracts from leaching plots at various sampling dates

1	2	3	4	5	6	7	8
			Electrical conductivity of 1:1 extract ($EC_1 x10^3$)				
Site	Treatment	Soil depth	Before leaching	After leaching	Pre-sowing 9/46	Spring 3/47	Harvest 7/47
	feet of water	*feet*	*millimhos/cm.*				
A	0	1	36.8*	34.2	40.1	22.1	21.7
		2	22.6	20.1	....	24.6	19.8
		3	16.9	15.9	....	17.3	16.2
		4	14.1	14.5	....	16.9	14.4
A	1	1	38.9	14.6	17.7	11.1	10.1
		2	20.6	15.5	....	16.8	14.5
		3	15.2	14.3	....	18.2	15.4
		4	12.8	13.4	....	17.8	16.0
A	2	1	33.7	6.4	8.6	6.2	7.7
		2	20.4	9.6	....	10.5	10.7
		3	13.9	12.4	....	15.5	14.2
		4	12.5	11.9	....	16.5	15.3
A	4	1	38.8	4.4	3.5	4.1	4.6
		2	21.3	6.1	....	5.4	5.9
		3	15.4	9.8	....	10.1	9.2
		4	13.3	11.0	....	11.7	10.4
A	4 plus gypsum	1	35.9	5.2	5.2	5.0	6.0
		2	19.8	5.7	....	6.2	7.6
		3	14.2	9.5	....	10.1	9.9
		4	12.5	10.2	....	11.6	10.9
C	0	1	30.3	30.4	35.2	16.7	16.0
		2	14.7	11.7	....	17.3	15.4
		3	8.3	7.8	....	13.6	13.2
		4	5.5	6.2	....	7.8	9.1
C	1	1	28.9	14.9	16.4	8.5	8.8
		2	15.2	12.6	....	10.5	11.2
		3	7.2	8.9	....	9.2	10.1
		4	4.3	6.3	....	8.5	7.9
C	2	1	31.5	7.9	9.1	7.2	8.6
		2	15.6	9.5	....	8.1	10.9
		3	9.1	9.7	....	8.2	9.4
		4	6.2	8.1	....	7.9	7.8
C	4	1	31.2	5.3	2.9	4.7	5.7
		2	16.2	5.0	....	4.5	7.8
		3	8.5	6.0	....	4.6	6.9
		4	4.7	6.2	....	5.5	6.1

Table 1. (Continued)

1	2	3	4	5	6	7	8
			Electrical conductivity of 1:1 extract ($EC_1 x 10^3$)				
Site	Treatment	Soil depth	Before leaching	After leaching	Pre-sowing 9/46	Spring 3/47	Harvest 7/47
	feet of water	*feet*			*millimhos/cm.*		
C	4 plus gypsum	1	32.7	5.4	6.5	4.3	5.4
		2	14.1	4.2	....	3.4	5.7
		3	8.4	5.4	....	4.4	6.3
		4	5.1	5.9	....	5.0	5.2
D	0	1	12.6	13.8	13.2	2.3	2.7
		2	16.4	15.1	....	9.0	7.5
		3	13.4	13.8	....	11.1	9.0
		4	12.0	12.2	....	13.0	9.6
D	1	1	12.7	3.9	3.4	1.9	2.7
		2	17.5	11.0	....	6.4	5.7
		3	15.3	12.8	....	9.6	7.7
		4	13.1	13.6	....	11.4	9.1
D	2	1	12.1	2.8	4.4	1.3	2.3
		2	16.1	6.5	....	4.5	4.8
		3	13.9	8.5	....	5.9	5.5
		4	12.1	9.3	....	7.0	6.7
D	4	1	13.0	2.6	1.9	1.3	2.4
		2	17.2	3.7	....	2.5	4.5
		3	16.1	4.8	....	3.9	5.2
		4	14.8	6.1	....	4.6	5.0
D	4 plus gypsum	1	11.8	3.0	3.4	2.2	2.5
		2	16.2	3.8	....	3.6	3.9
		3	13.7	4.8	....	3.6	3.8
		4	12.8	6.0	....	4.0	5.0

*All values are averages of four replicates except those for the pre-sowing sampling which are averages of two replicates.

Table 2. Chemical data for soils from leaching plots at sites A, C and D

1	2	3	4	5	6	7	8	9
Site and plot no.	Treatment	Time of sampling	Soil depth	Saturation percentage	pH	Gypsum	Cation exchange capacity	Exchangeable sodium
	feet of water		*feet*	*percent*		*m.e/100 gm.*	*m.e/100 gm.*	*percent*
A-7	2 ft.	Before leaching	1	47.0	7.80	3.7	21.2	26
			2	60.3	7.90	2.5	28.2	28
			3	61.7	7.90	5.3	31.7	30
			4	48.7	7.80	5.1	24.2	38
A-7	2 ft.	After leaching	1	47.8	7.85	0.6	19.5	17
			2	64.0	7.80	1.6	27.0	23
			3	72.2	7.80	5.0	33.2	24
			4	55.7	7.75	6.8	28.6	28
A-7	2 ft.	Harvest	1	44.0	7.90	0.9	20.2	13
			2	64.0	7.90	1.0	27.4	23
			3	67.3	7.80	2.3	30.6	26
			4	49.6	7.80	4.6	25.2	30
A-5	4 ft.	Before leaching	1	42.6	7.90	7.5	18.5	40
			2	60.2	8.05	6.0	24.8	36
			3	75.6	8.10	6.7	33.8	29
			4	62.8	8.00	5.6	27.9	27
A-5	4 ft.	After leaching	1	42.7	8.00	2.2	19.4	14
			2	59.3	7.90	1.1	24.3	24
			3	69.0	7.90	3.8	31.2	22
			4	57.0	7.90	7.3	26.6	31
A-5	4 ft.	Harvest	1	43.3	7.80	0.8	19.8	14
			2	47.0	8.00	1.1	24.9	23
			3	66.5	7.90	3.7	31.9	24
			4	57.0	8.00	7.1	27.3	32
A-4	4 ft. + gyp.*	Before leaching	1	44.0	8.10	13.6	18.1	37
			2	57.4	8.05	5.4	22.5	24
			3	72.5	8.00	5.5	34.4	22
			4	70.4	7.90	1.3	33.7	24
A-4	4 ft. + gyp.	After leaching	1	41.2	7.85	7.8	19.7	12
			2	56.0	8.00	2.4	26.2	23
			3	78.5	7.80	3.0	33.4	21
			4	60.7	7.75	2.3	32.3	26
A-4	4 ft. + gyp.	Harvest	1	44.5	7.90	6.2	19.6	15
			2	55.2	8.00	2.2	24.6	22
			3	68.6	7.90	2.7	32.9	23
			4	68.0	7.90	1.0	31.8	26

10	11	12	13	14	15	16	17	18
	Analysis of saturation extract							Soluble salts in soil
Electrical conductivity	Cations			Anions			Soluble sodium	
	Ca	Mg	Na	HCO_3	Cl	SO_4		
millimhos/cm	*m.e/l.*	*m.e/l.*	*m.e/l.*	*m.e/l.*	*m.e/l.*	*m.e/l.*	*percent*	*percent*
55.5	100	144	433	6	583	80	65	1.82
32.6	54	63	272	4	321	82	67	1.42
22.2	37	35	195	3	168	99	73	1.02
22.8	39	36	198	4	178	97	73	.82
9.7	20	21	71	4	47	72	63	.36
13.5	26	21	109	4	65	97	68	.67
16.3	28	24	133	4	90	101	68	.88
21.8	35	35	178	4	132	101	72	.83
9.0	23	24	63	4	67	42	58	.30
13.2	22	22	110	4	82	74	69	.63
17.1	30	29	148	3	104	101	71	.88
25.0	41	47	212	4	201	102	71	.92
76.6	90	218	694	5	880	112	69	2.44
38.2	56	73	307	2	345	93	70	1.56
21.0	35	34	175	2	151	93	71	1.14
21.2	38	36	170	2	155	89	70	.94
9.4	31	29	59	8	36	79	50	.33
9.6	24	17	89	6	38	84	70	.50
10.0	19	19	90	4	27	101	70	.60
15.0	31	27	142	5	88	109	71	.71
14.0	44	47	84	4	117	62	48	.47
12.0	20	24	95	2	74	68	66	.41
14.9	29	27	126	4	86	87	71	.75
19.2	33	35	166	3	133	109	71	.86
70.6	67	100	722	5	740	117	81	2.25
33.6	50	46	284	2	290	86	75	1.30
20.2	39	29	164	2	148	77	71	1.01
19.4	40	28	147	2	144	75	68	.94
8.0	23	9	45	4	22	69	51	.25
10.4	28	10	86	3	22	104	69	.48
11.4	24	16	93	4	34	99	69	.69
15.2	28	22	126	4	86	93	69	.70
12.5	37	27	82	3	75	75	55	.42
13.3	30	19	107	3	75	82	67	.55
13.0	28	20	110	2	77	80	70	.69
14.2	29	23	124	2	96	86	70	.77

Table 2. (Continued)

1	2	3	4	5	6	7	8	9
Site and plot no.	Treatment	Time of sampling	Soil depth	Saturation percentage	pH	Gypsum	Cation exchange capacity	Exchangeable sodium
	feet of water		*feet*	*percent*		*m.e/100 gm.*	*m.e/100 gm.*	*percent*
C-12	2 ft.	Before leaching	1	38.7	7.90	10.1	16.0	34
			2	39.1	8.00	4.2	17.4	29
			3	43.2	7.80	0.3	20.0	23
			4	39.9	7.90	0.3	16.4	22
C-12	2 ft.	After leaching	1	41.2	7.70	4.4	17.7	22
			2	41.0	7.70	0.9	18.1	23
			3	47.2	7.85	0.5	18.4	25
			4	41.4	7.80	0.5	17.3	25
C-12	2 ft.	Harvest	1	38.2	7.80	4.0	16.8	16
			2	42.0	7.90	2.3	17.2	17
			3	39.8	7.90	1.3	19.4	26
			4	40.0	7.80	0.4	16.8	23
C-10	4 ft.	Before leaching	1	44.9	7.95	6.9	18.7	31
			2	50.0	8.05	6.0	20.8	41
			3	49.3	8.15	0.4	18.7	28
			4	42.8	8.25	0.4	16.0	27
C-10	4 ft.	After leaching	1	44.2	7.80	4.0	17.9	16
			2	46.5	7.80	1.6	21.8	16
			3	46.5	7.85	1.0	19.6	28
			4	42.5	7.70	0.2	16.6	25
C-10	4 ft.	Harvest	1	44.5	7.80	0.4	17.1	14
			2	48.0	7.80	1.3	21.1	15
			3	43.4	7.80	0.3	18.8	25
			4	38.7	7.90	0.0	15.5	26
D-4	4 ft. + gyp.	Before leaching	1	55.0	7.50	1.2	33.2	16
			2	38.5	7.50	7.6	17.4	16
			3	28.7	7.45	4.1	14.0	23
			4	27.5	7.40	2.5	14.4	16
D-4	4 ft. + gyp.	After leaching	1	69.5	7.80	2.4	33.9	6
			2	41.0	7.75	2.7	17.4	11
			3	30.6	7.95	3.5	13.9	12
			4	28.5	7.90	2.8	14.4	11
D-19	4 ft.	Before leaching	1	57.0	7.60	1.4	36.0	11
			2	58.5	7.50	5.2	34.1	10
			3	41.5	7.30	4.1	19.3	20
			4	41.5	7.40	5.6	18.5	17
D-19	4 ft.	After leaching	1	61.4	8.00	0.5	37.2	7
			2	63.2	7.80	0.9	32.8	10
			3	41.2	7.70	2.0	19.3	15
			4	39.2	7.70	2.4	18.5	19

*Gypsum was applied at the rate of 5 tons per acre before leaching on plots where gypsum treatment is indicated.

10	11	12	13	14	15	16	17	18
	Analysis of saturation extract							Soluble salts in soil
Electrical conductivity	Cations			Anions			Soluble sodium	
	Ca	Mg	Na	HCO_3	Cl	SO_4		
millimhos/cm	*m.e/l.*	*m.e/l.*	*m.e/l.*	*m.e/l.*	*m.e/l.*	*m.e/l.*	*percent*	*percent*
73.3	93	221	682	12	838	161	68	2.26
24.3	42	57	201	4	191	104	67	.71
13.2	18	26	105	4	94	57	68	.41
10.9	14	16	84	4	77	38	71	.25
17.9	37	55	126	5	123	97	58	.56
16.6	30	44	126	3	105	95	62	.51
15.6	25	40	125	3	109	72	65	.54
18.0	31	51	131	3	133	74	62	.53
12.0	35	42	80	6	65	86	51	.37
14.4	33	41	116	4	82	102	62	.50
14.6	24	37	116	3	99	77	65	.44
17.0	28	47	127	3	129	73	62	.48
60.5	69	193	527	4	650	114	68	2.00
20.1	30	44	161	3	125	105	69	.71
11.8	14	23	91	2	79	49	70	.38
9.4	10	18	71	2	62	31	72	.25
12.1	32	38	76	4	62	83	52	.42
9.8	26	23	71	3	33	87	59	.37
14.6	20	28	110	3	95	65	67	.46
19.2	31	46	137	4	141	73	63	.47
5.6	13	15	35	4	30	30	55	.16
9.1	29	26	60	3	44	68	52	.35
11.3	15	25	91	4	69	59	69	.36
13.0	17	30	104	3	87	62	68	.36
19.4	63	38	102	4	174	44	46	.69
27.0	67	60	177	3	246	57	58	.68
20.8	48	45	141	4	166	70	60	.41
17.3	43	38	112	4	129	68	56	.33
5.4	24	12	28	3	15	49	44	.30
6.8	29	14	40	2	20	60	50	.22
8.2	29	12	53	3	26	70	56	.33
8.5	29	14	58	3	27	74	58	.19
21.6	67	58	109	2	202	31	46	.76
28.1	80	81	159	3	270	50	49	1.08
36.4	108	127	201	4	382	49	46	1.02
33.3	103	118	181	3	338	50	46	.92
3.0	6	5	18	4	13	14	58	.12
5.6	24	9	33	3	10	57	50	.28
6.8	28	17	47	3	18	70	52	.24
10.1	31	13	70	3	38	84	56	.31

Table 3. Moisture retention data for Delta soils at sites A, C, and D

1	2	3	4	5	6	7
Site and plot no.	Soil depth	Saturation moisture content	One-third atmosphere moisture content*	Fifteen atmosphere moisture content†	One-third minus fifteen atmosphere moisture content	Available-water capacity‡
	feet	*percent*	*percent*	*percent*	*percent*	*inches*
A-1	1	45.9	28.8	11.3	17.5	3.1
A-2	1	45.2	28.3	11.2	17.1	3.0
	2	66.4	32.2	13.9	18.2	3.2
	3	86.6	35.4	20.2	15.2	2.7
	4	73.7	32.5	16.0	16.5	2.9
A-3	1	48.4	29.7	11.6	18.1	3.2
A-9	1	48.6	30.0	12.2	17.8	3.1
	2	76.2	35.4	17.7	17.7	3.1
	3	78.2	35.0	18.1	16.9	3.0
	4	57.1	30.1	13.5	16.6	2.9
A-12	1	52.8	29.9	13.4	16.4	2.9
A-18	1	47.5	29.0	12.1	16.9	3.0
	2	88.8	35.3	19.3	16.0	2.8
	3	72.8	35.1	19.3	15.8	2.8
	4	72.3	32.7	16.7	16.0	2.8
Averages	1					3.1
by	2					3.0
depths	3					2.5
	4					2.5
C-2	1	50.9	26.8	11.1	15.7	2.8
	2	54.3	26.1	10.8	15.3	2.7
	3	44.0	21.5	7.9	13.6	2.4
	4	39.7	18.4	7.5	10.9	1.9
C-9	1	44.5	26.2	10.2	16.0	2.8
	2	47.7	23.6	10.2	13.4	2.4
	3	50.9	25.2	10.6	14.6	2.6
	4	45.8	23.0	10.3	12.7	2.2
C-15	1	48.5	26.5	10.5	16.0	2.8
C-16	1	50.7	23.4	9.4	14.0	2.5
	2	55.5	25.9	11.5	14.4	2.6
	3	47.8	24.9	10.2	14.7	2.6
	4	41.2	19.9	7.7	12.2	2.2
C-18	1	47.3	24.1	9.4	14.7	2.6
C-20	1	51.9	24.3	9.4	14.9	2.6
Averages	1					2.7
by	2					2.6
depths	3					2.5
	4					2.1

Table 3. (Continued)

1	2	3	4	5	6	7
Site and plot no.	Soil depth	Saturation moisture content	One-third atmosphere moisture content*	Fifteen atmosphere content†	One-third minus fifteen atmosphere moisture content	Available-water capacity‡
	feet	*percent*	*percent*	*percent*	*percent*	*inches*
D-1	1	61.6	34.1	19.8	14.3	2.5
D-2	1	63.2	34.4	19.6	14.8	2.6
	2	50.1	28.0	12.8	15.2	2.7
	3	36.2	13.4	5.5	7.9	1.4
	4	33.7	11.9	4.8	7.1	1.3
D-3	1	66.4	33.0	18.8	14.2	2.5
D-9	1	63.6	32.5	18.3	14.2	2.5
	2	48.2	25.9	11.1	14.8	2.6
	3	38.8	16.2	6.5	9.7	1.7
	4	38.1	14.8	5.8	9.0	1.6
D-15	1	64.2	35.3	20.7	14.6	2.6
D-17	1	69.8	36.0	19.4	16.6	2.9
	2	66.3	32.9	17.7	15.2	2.7
	3	47.1	24.2	9.1	15.1	2.6
	4	49.4	24.5	9.4	15.1	2.6
Average by depths	1					2.6
	2					2.7
	3					1.9
	4					1.8

*The one-third atmosphere moisture percentage approximates field moisture capacity, or the upper limit of usable soil moisture.

†The fifteen atmostphere moisture percentage falls within the wilting range for most plants and approximates the wilting percentage, or lower limit of available soil moisture.

‡Calculated from the following expression which is based on an assumed soil specific gravity of 1.47: ($\frac{1}{3}$ atmosphere percentage −15 atmosphere percentage) $\times$ .177 $=$ inches of available water.

Table 4. Soil salinity, yields, and test weights of wheat from leaching plots

1		2	3	4	5	6	7	8	9	10
		Site A			Site C			Site D		
Plot no.	Treatment	Soil salinity* (ECe×10³)	Yield†	Test weight	Soil salinity (ECe×10³)	Yield	Test weight	Soil salinity (ECe×10³)	Yield	Test weight
	ft. water	*millimhos/cm*	*bu/ac*	*lbs/bu*	*millimhos/cm*	*bu/ac*	*lbs/bu*	*millimhos/cm*	*bu/ac*	*lbs/bu*
1	0	41.2	0.1	....	24.2	7.0	....	7.0	29.2	61.2
6		42.1	0.3	....	27.4	9.1	61.7	7.3	20.2	62.0
13		31.0	2.0	....	36.0	0.6	....	6.2	39.3	62.7
16		20.6	0.4	59.3	29.2	4.0	....	9.8	26.2	60.0
	Average	33.7	0.7	59.3	29.2	5.2	61.7	7.6	28.7	61.5
3	1	24.2	7.1	....	20.0	21.1	63.0	6.8	18.1	60.7
8		22.1	14.1	....	8.0	33.3	63.0	5.7	26.2	62.0
11		14.1	17.1	59.0	22.4	12.1	....	5.4	32.2	62.5
20		13.5	16.1	59.0	14.3	28.2	62.2	5.6	27.2	62.0
	Average	18.5	13.6	59.0	16.2	23.7	62.7	5.9	25.9	61.8
2	2	17.3	16.1	57.5	9.2	49.4	63.0	5.2	22.2	63.0
7		9.7	30.2	62.7	14.2	21.2	62.5	4.2	37.3	62.0
12		8.7	21.2	61.2	13.8	37.3	62.0	4.0	36.3	62.5
15		13.5	26.2	61.0	22.1	17.1	61.5	4.1	39.3	63.0
	Average	12.3	23.4	60.6	14.8	31.3	62.3	4.4	33.8	62.6
5	4	10.0	34.2	61.8	11.5	37.3	62.8	4.8	38.3	63.2
10		7.0	47.4	63.0	6.3	51.4	62.5	3.5	43.3	63.2
18		5.7	49.4	63.0	10.5	45.4	62.8	3.3	37.3	62.8
19		6.0	39.3	62.5	9.9	38.3	61.5	3.2	45.4	63.0
	Average	7.2	42.6	62.6	9.6	43.1	62.4	3.7	41.1	63.1
4	4	11.5	33.2	60.0	6.7	41.3	62.5	5.1	34.3	63.5
9	plus gypsum	9.9	38.3	62.2	8.2	35.3	63.0	4.9	39.3	63.0
14	(5 tons	7.7	42.3	63.0	7.6	34.3	62.5	3.8	44.4	63.0
17	per acre)	5.8	37.3	62.3	11.7	40.3	62.5	3.3	46.4	63.7
	Average	8.7	37.8	61.9	8.6	37.8	62.6	4.3	41.1	63.3

*Soil salinity is given in terms of conductivity of the saturation extract of the soil from 0 - 2 ft. depth in millimhos per cm. (ECe×10³). The values given are averages of determinations made at the beginning of the growing season (March 1947) and at the time of harvest (July 1947).

†Yield values are based upon the standard test weight of 60 lbs./bushel.

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